Advanced Vibration Analysis

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"One step in your journey to benchmark status"

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Advanced Vibration Analysis

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Important News on Future RBMware Releases and Windows Operating Systems

Dear CSI customer,

CSI would like to take this opportunity to inform you of our plans for supporting various computer operating systems for future releases of RBMware. This information is being provided so you can plan ahead for any necessary system upgrades.

CSI is pleased to announce version 4.60 of RBMware will introduce support for Windows 2000 with Service Pack 1 and later (SP1+). This release is due in late summer 2001, and a mass update is planned for all customers who have RBMware under warranty or maintenance agreement at that time.

CSI has also made a decision to discontinue support for Windows 95 and 98 in future RBMware releases. The result is that RBMware will only be supported on Windows NT and Windows 2000 (SP1+) for the RBMware release tentatively scheduled for late spring 2002. We are notifying customers and field organizations well in advance so necessary plans can be made.

Customers who wish to remain on Windows 95/98 will continue to receive full technical support of RBMware 4.60 and MasterTrend as long as they remain on maintenance agreement. Once they upgrade their operating system to Windows NT or Windows 2000 (SP1+), they can update to the current RBMware version and begin realizing benefits of the many advanced features and capabilities.

Why NT and 2000?
As RBMware continues to evolve and meet the increasingly complex needs of our customers, it requires a more robust environment in which to operate efficiently. The increased speed, advanced networking capabilities, security, and reliability of Windows NT and Windows 2000 enable our customers to work more efficiently and with fewer difficulties.

We also want our customers to implement platforms on which they will continue to receive upgrades and support as their needs change or technical difficulties arise. Microsoft is ending support of the Windows 95 operating system in late 2001 with Windows 98 soon to follow. This means consumers will no longer be able to get platform support from Microsoft for these operating systems.

If you are currently running Windows 95 or 98, we recommend that you upgrade to Windows 2000 (SP1+).

What about Windows ME?
Microsoft has positioned Windows ME to be the solution of choice for the home PC and gamers. It is basically an upgrade or replacement for Windows 98. Most home-use PCs that are purchased in stores such as Best Buy and Circuit City are pre-loaded with Windows ME, while business system PCs come standard with Windows 2000 Professional.

RBMware, version 4.60 installation and update CDs will not support or install on Windows ME. If you are currently running Windows ME, we recommend that you upgrade to Windows 2000 (SP1+).

Important Platform Information for RBMware

RBMware version 4.60	Will not install on Windows ME
	Last RBMware version supporting Windows 95/98
	First RBMware version supporting Windows 2000 (SP1+)
RBMware version 4.70	Will not install on Windows ME/95/98
	Continued support for Windows NT and Windows 2000 (SP1+)

Note: MasterTrend will not support Windows 2000 or Windows ME operating systems.

Thank you again for your continued use and support of CSI products and services,

Drew Mackley
Emerson Process Management, CSI Division
CSI Diagnostic Software Marketing Manager
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June, 2001

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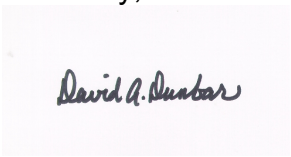
February 1, 2002

Dear CSI Training Customer,

We are pleased to have the opportunity to provide you training services from CSI. The investment your company makes in technology and preventative maintenance systems can only deliver value when placed in the hands of trained and qualified personnel. You are taking an important step toward ensuring the long-term success of your Reliability-Based Maintenance program in seeking continuous improvement through Reliability Education,

It is our desire that your training experience at CSI be valuable and personally rewarding. If you feel that any aspect of the training experience could be enhanced or otherwise improved please let your instructor know at the end of your training session.

Sincerely,



David A. Dunbar
President

CSi

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Introduction

Section 1

Objectives

- Recognize the importance of advanced vibration analysis methods.
- Understand that the method of course instruction will be a combination of discussion and lab work.

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Overview

This course will cover the integration of many available advanced analysis data collection techniques into your RBM program using CSI's MasterTrend or RBMware software and Model 2120 Machinery Analyzer.

These techniques include:

- PeakVue Detection
- Slow Speed Technology
- Two-Channel Data Collection
- Zoom Analysis
- Orbit Plots
- Phase Analysis
- Transient Analysis
- Waveform Analysis Parameters
- Resonance Detection
- Triggered Data Collection

In this course, students will be encouraged to begin using the power of these new techniques to solve complex vibration problems. Each of the analysis techniques is presented from the MasterTrend or RBMware perspective, using the 2120 analyzer.

Most of the 2120's advanced features can be controlled from MasterTrend or RBMware. Some of the features can be selected only at the analyzer and the resulting measurements can be stored and dumped back to the MasterTrend or RBMware database for later viewing in the Diagnostic Plotting program.

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The combination of the advanced features of the CSI 2120 Machinery Analyzer with a route-based data collection procedure can greatly improve your ability to make both early and more accurate machine diagnoses.

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Digital Signal Processing

Section 2

Objectives

- Relate time waveform length and frequency bandwidth to sampling rate and sample size.
- Choose the correct analysis window for each vibration analysis opportunity.
- Recognize limitations of digital signal processing.

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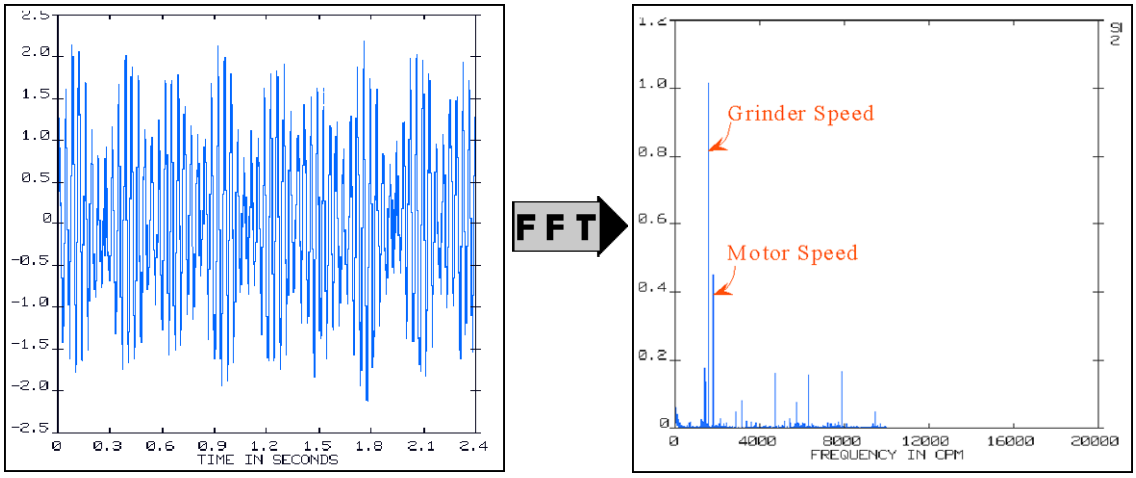
Fast Fourier Transform

The conversion of time domain information to frequency domain information is the Fast Fourier Transform (FFT).



Often a frequency spectrum is referred to as an FFT. However, the FFT refers to the mathematical conversion from the time domain to the frequency domain.

Since the signal that comes into the analyzer is an analog signal as discussed in the previous section, it must be digitally sampled by the analyzer. Therefore, the process used by digital analyzers is actually a variation of the FFT called the *Discrete Fourier Transform* (DFT).

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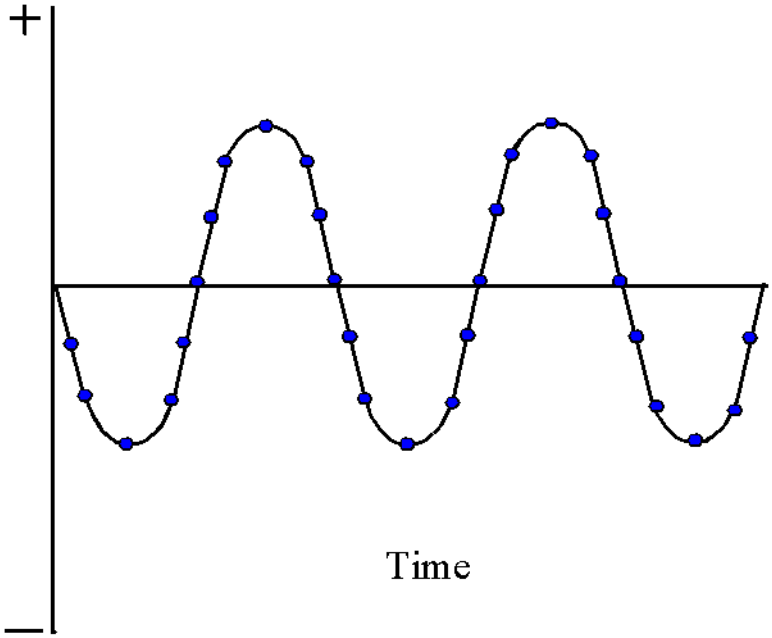
For the DFT, the time waveform is recreated in the analyzer by digital sampling; then it is transformed into the frequency domain. The FFT process works based on the assumption that the signal measured and digitally sampled is a periodic signal that extends from minus infinity to plus infinity. Normally, this is true for most vibrating pieces of equipment.



Instantaneous Sampling - Normal Processing

It is the digital sampling process that makes the signal processing more complicated. The information here unlocks the mysteries of digital signal processing without getting bogged down in too much theory.

In order to understand the FFT digital sampling process, you must understand the relationship between lines of resolution (LOR) maximum frequency (F_{max}), length of time waveform (T_{max}), the digital sample size, filters, and unit conversion.

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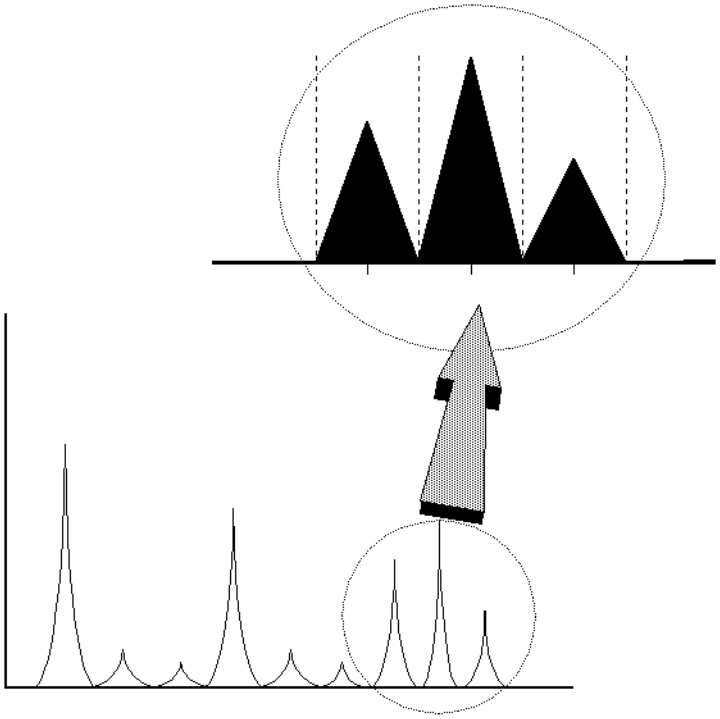
Resolution (LOR)

Once data has been converted to the frequency domain from the time domain, view all the frequencies of interest in as much detail as possible. *Resolution* is the number of parts of the spectrum, usually called lines of resolution (LOR). The number of lines of resolution selected are divided into the maximum analysis frequency (F_{max}) to arrive at the bandwidth (BW).

$$\mathbf{BW = F_{max} / LOR}$$



The lines are actually the center frequencies of what are often called *bins of energy*. Each bin actually contains an infinite number of frequencies and all the energy in the bin is summed and represented by a single amplitude at the center frequency identified at each line of resolution.

First, identify your frequencies of interest so that enough resolution is chosen to separate closely spaced frequencies. A common LOR for PeakVue is **1600 lines**. Also, be aware that more lines of resolution affect the length of the time waveform. For normal trending, we have to weigh the pros and cons of higher resolution.

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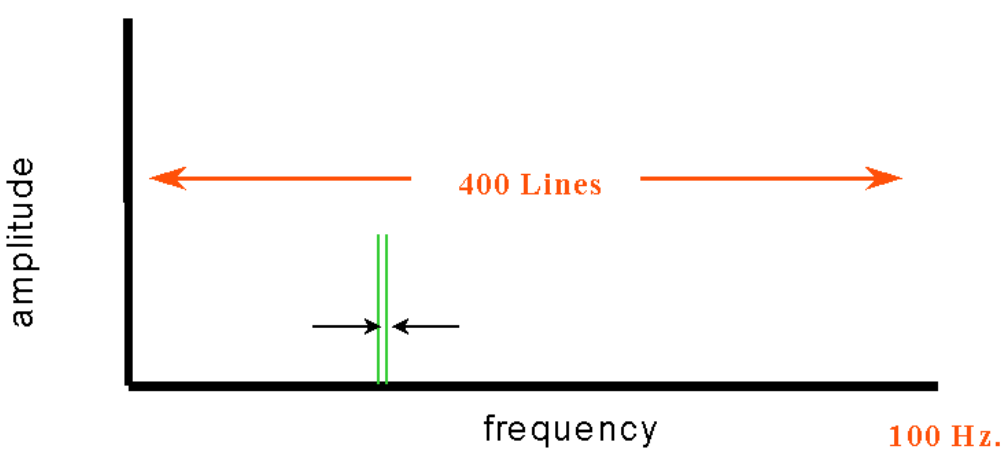
Remember that the time to collect one average is equal to one divided by the bandwidth. As the bandwidth decreases, the data collection time increases. The bandwidth (**BW**) should be no greater than 5 Hz/Line. This will give adequate resolution for identifying trend changes and reasonable data collection time.



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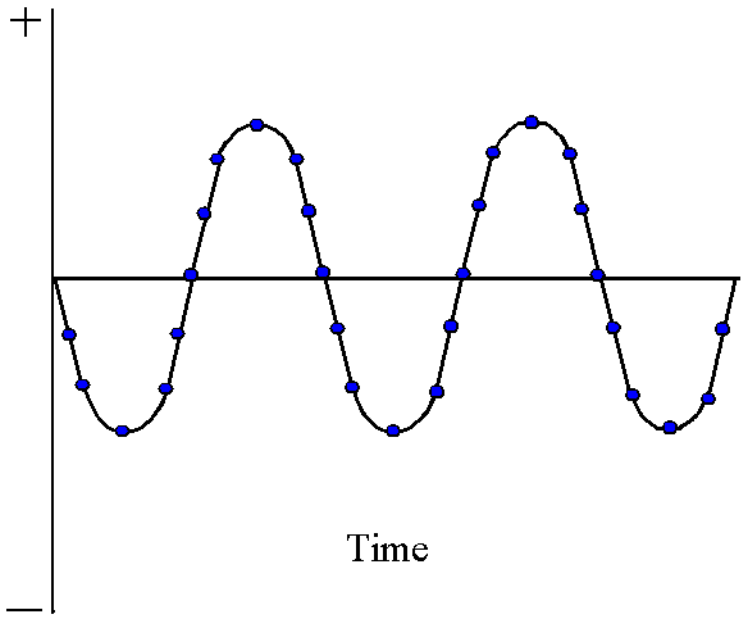
Maximum Frequency (F_{max})

One popular way of setting $\mathbf{F_{max}}$ is to use an order-based set based on the turning speed of the shaft being monitored. Let's take a look at the effect of RPM on the **Sample Rate** with a typical **70x Turn Speed Rolling Element Bearing Set**.

RPM	RPM x 70 = F_{max}	F_{max} * 2.56 = Sample Rate
60 Hz (3600 CPM)	4,200	10,752 / sec
20 Hz (1200 CPM)	1,400	3584
1 Hz (60 CPM)	70	179

The drawing below represents the sampling of instantaneous values to represent a sine wave. As the bandwidth or F_{max} is lowered, the sampling rate decreases making high frequency vibrations difficult, if not impossible, to measure.



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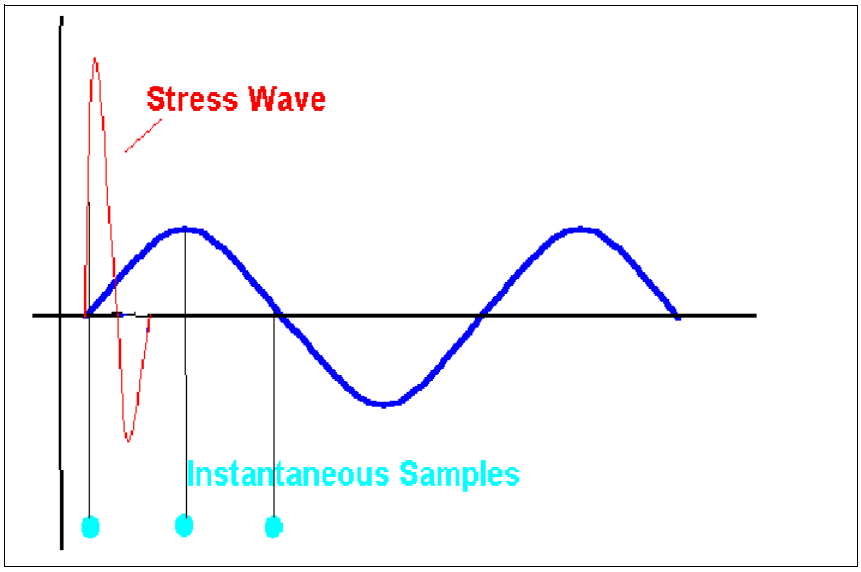
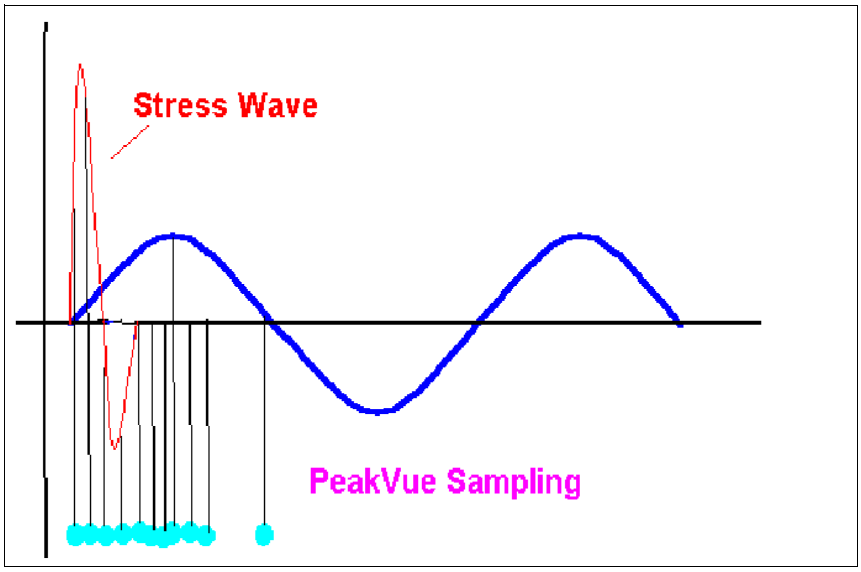
Stress waves occur above 1000 Hz. With a low sampling rate, stress waves may be missed.



Sampling Rate Limitations - Normal Processing

PeakVue's near 100K sampling rate, pre-filtering and peak hold signal processing insure the capture of stress wave energy. Stress waves produced from metal to metal impacting are captured and displayed in the time waveform and spectrum. PeakVue data is trendable.



Sampling Rate Example - PeakVue Processing

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Time Record Length

Calculate the time record length of the time waveform, T_{max}, from the following basic relationships.

$$\mathbf{T_{max} = 1 / BW}$$

or

$$\mathbf{T_{max} = LOR / F_{max}}$$

or

$$\mathbf{T_{max} = Sample\ size / Sample\ rate}$$

At face value, this is a simple and often used equation. However, to understand the limitations of some analyzers, it is important to more fully investigate the relationship between the F_{max}, the LOR, and the T_{max}.

To insure an analog waveform is sampled often enough, DSA's sample at the **Nyquist rate**. The Nyquist rate is 2.56 and results in a sample rate that is 2.56 times the frequency range selected.

The sample rate is the number of digital samples per second made in the time waveform measurement.

$$\mathbf{Sample\ rate = 2.56 * F_{max}}$$

Example: A spectrum acquired to 100 Hertz F_{max} will result in an analyzer sample rate of 100 * 2.56 = 256 Hertz. Put another way, the analyzer will sample the incoming waveform at a rate of 256 samples per second in order to display the 100 Hertz spectrum requested.

The waveform sample size is the total number of digital samples made in the time waveform.

$$\mathbf{Sample\ size = 2.56 * Lines\ of\ Resolution}$$

Example: A spectrum acquired with 800 lines of resolution will have 800 * 2.56 = 2048 waveform samples.

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Some analyzers have an upper limit on the sample size. ***The 2120 analyzer can store waveforms with up to 4,096 samples***. Using the sample size calculation from above, the following are true:

a 400-line spectrum would require 2.56 * 400 = 1,024 samples
a 800-line spectrum would require 2.56 * 800 = 2,048 samples
a 1600-line spectrum would require 2.56 * 1600= 4096 samples
a 3200-line spectrum would require 2.56 * 3200= 8,192 samples
a 6400-line spectrum would require 2.56 * 6400= 16,384 samples

Even though the 3200 and 6400-line spectrums have more than 4096 waveform points, they can be measured and viewed on the 2120. Only 4,096 samples are stored when the data is saved since it is the upper limit of the analyzer. This is important when discussing the T_{max} in the time waveform, because, in general, raising the F_{max} decreases T_{max}, and raising LOR increases T_{max} to the point that the product of 2.56 * LOR reaches the stored sample limit in the analyzer. The waveform sample size, for any measurement greater than 1600 lines, is forced to be 4,096.

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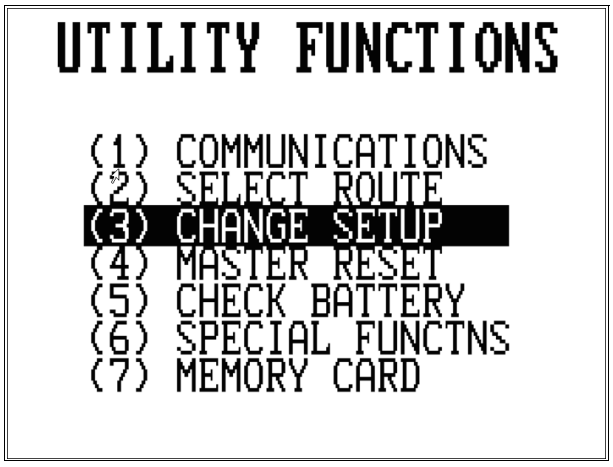
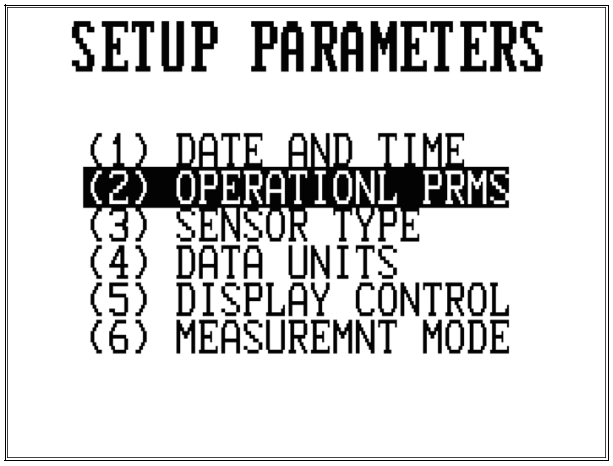
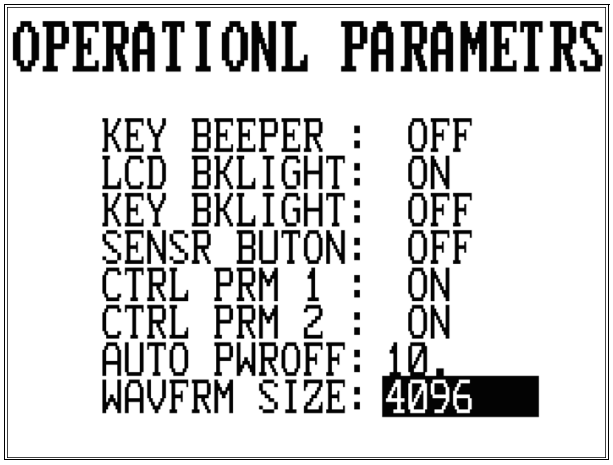
The waveform sample size in the 2120 analyzer is controlled from the UTILITY menu. Waveform sample size is adjustable between 50-4096 samples. Smaller sample size results in shorter time waveforms. CSI recommends 1024 or 2048 samples for routine data collection.







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Be aware of the waveform size setting on the analyzer. It will determine how much of the collected time waveform is saved to MasterTrend or RBMware and to the 2120 analyzer. If the setting is low, the waveforms will be practically useless for analysis. If the setting is too high, waveforms will take up computer disk space and analyzer RAM memory. The only software controlled override for the waveform size setting is in the parameter set if a special time waveform collection is specified.

Class Exercise:

Monitor the time waveform of a motor demonstrator using Analyze/Monitor/ Monitor Waveform. Look at the data with a waveform size of 50 samples. Increase the waveform size to 1024, 2048 and 4096.

The table below demonstrates how increasing sample size affects the T_{max} and shows the limitation for a maximum of 4,096 samples.

T_{max} = Sample size / Sample rate

F_{max}	Sample Rate (S_r) = F_{max} * 2.56	LOR	Sample Size (S_s) = LOR * 2.56	Time (sec) = S_s / S_r or LOR / F_{max}
400	1024	400	1024	1.00
400	1024	800	2048	2.00
400	1024	1600	4096	4.00
400	1024	3200	8192 (4,096 stored)	8.00 (4,096 stored)
400	1024	6400	16,384 (4,096 stored)	16.00 (4,096 stored)

The last two entries in the table may seem incorrect, but remember that 4,096 is the maximum sample size stored to MT or RBMware. Any waveform collected and displayed on the 2120, greater than 4,096 samples, is forced to be 4,096 samples when the waveform is stored (*the last 4096 samples are stored*).

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To increase the amount of time in the time record, it is necessary to adjust the F_{max} to a lower value. The following chart show the effect on the time record of various F_{max} settings.

F_{max}	Sample Rate (S_r) = F_{max} * 2.56	LOR	Sample Size (S_s) = LOR * 2.56	Time (sec) = S_s / S_r or LOR / F_{max}
1000	2560	1600	4096	1.6
400	1024	1600	4096	4
200	512	1600	4096	8
100	256	1600	4096	16
10 (L.F. limit)	25.6	1600	4096	160
10	25.6	3200	8192	320 (160 stored)
10	25.6	6400	16,384	640 (160 stored)

Hardware Integration and Differentiation

The vibration input signal into the analyzer is a time-varying voltage proportional to the vibration measured by the transducer. In other words, an accelerometer produces a voltage that varies over time relative to the acceleration measured by the transducer. The voltage amplitude in the time waveform is converted to the desired amplitude units based on the sensitivity and conversion factor of the transducer.

Most analyzers have the ability to convert from the measurement units of the transducer to either of the other two units in the time domain or the frequency domain. At CSI, integration of the time signal is called *analog* integration and integration of the frequency domain is called *digital* integration.

Integration is a process of converting from acceleration to velocity or displacement, or converting from velocity to displacement.

Differentiation is the process of converting from displacement to velocity or acceleration, or converting from velocity to acceleration.

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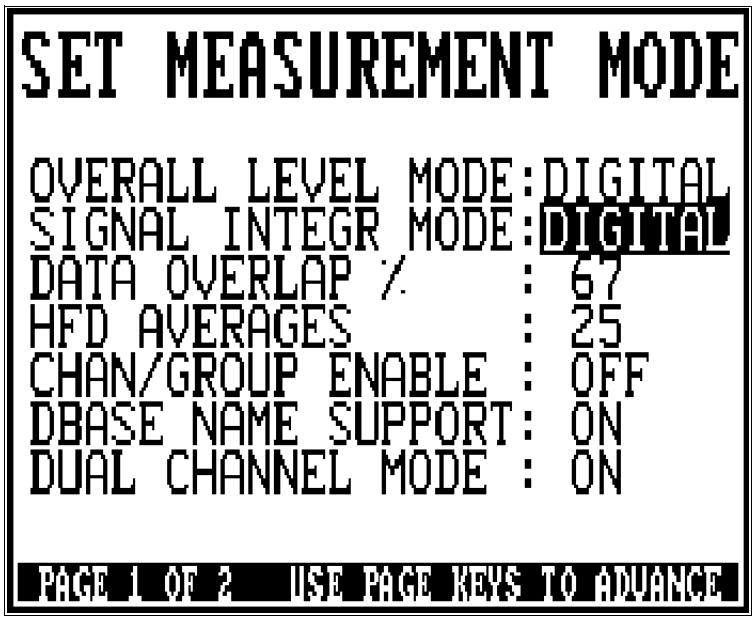
On the 2120 analyzer, the signal integration mode setting controls how the input signal is treated.


SET MEASUREMENT MODE
OVERALL LEVEL MODE: DIGITAL
SIGNAL INTEGR MODE: DIGITAL
DATA OVERLAP %: 67
HFD AVERAGES: 25
CHAN/GROUP ENABLE: OFF
DBASE NAME SUPPORT: ON
DUAL CHANNEL MODE: ON
PAGE 1 OF 2 USE PAGE KEYS TO ADVANCE

The help screen on the 2120 is useful to remember how the signal integration setting affects the time and frequency domains. CSI recommends ANALOG signal integration for the best analyzer performance, however....

...understand how the signal integration mode affects the data.

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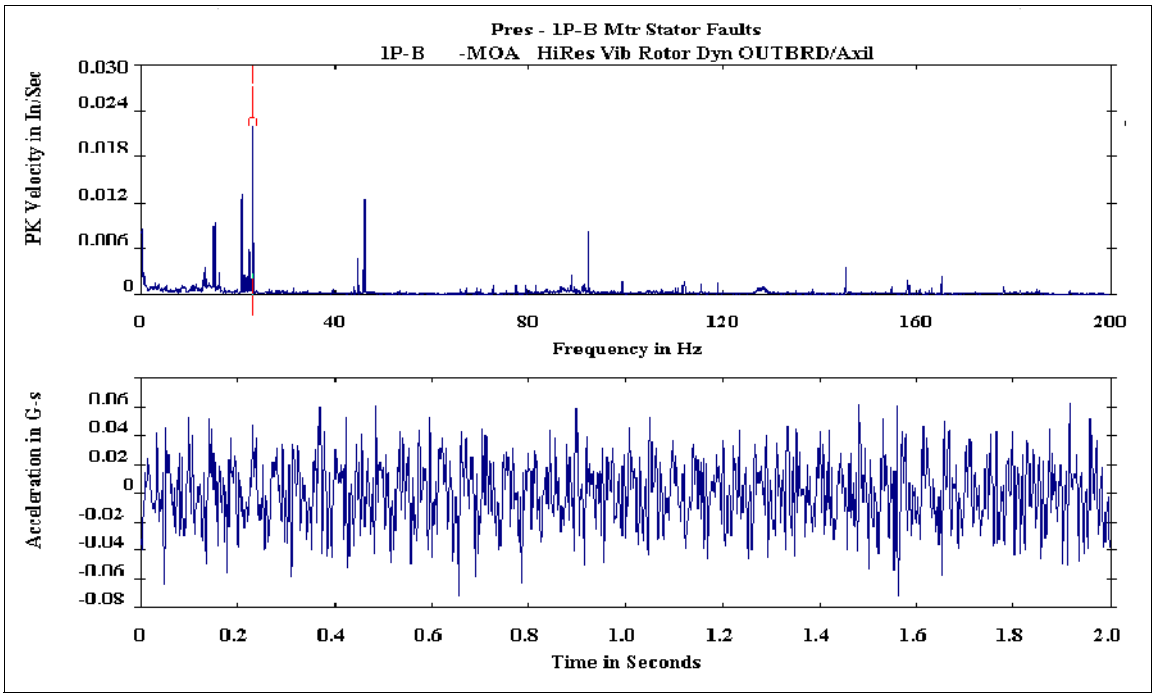
If route data is configured for velocity spectrums using an accelerometer and acceleration waveforms are desired, the analyzer must be set to Digital Integration. The display on the 2120 will show an acceleration waveform and a velocity spectrum.



In RBMware, the spectrum and waveform display can always be converted to other measurement units. The waveform cannot be converted in MasterTrend.

There is no right or wrong selection for signal integration mode. The choice depends on what the analyst is looking for in the time waveform and the preference for spectral units on the 2120 display.

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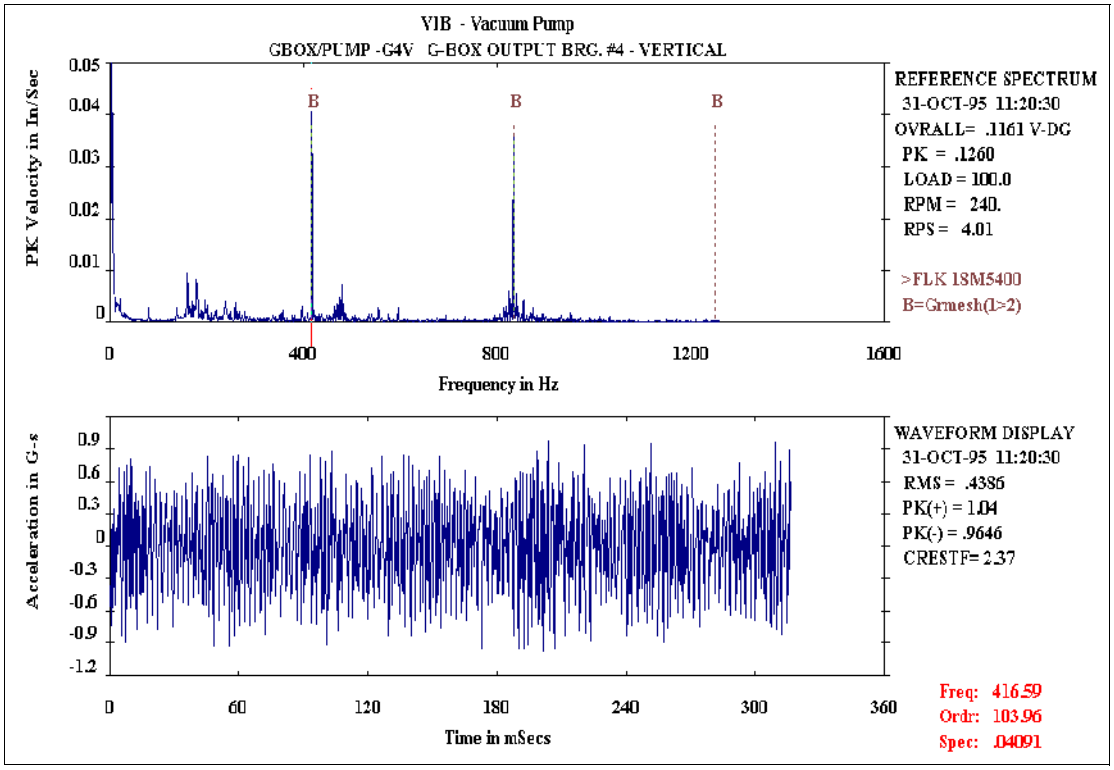
Acceleration waveforms are useful for analyzing bearing and gearbox faults and other high frequency problems.



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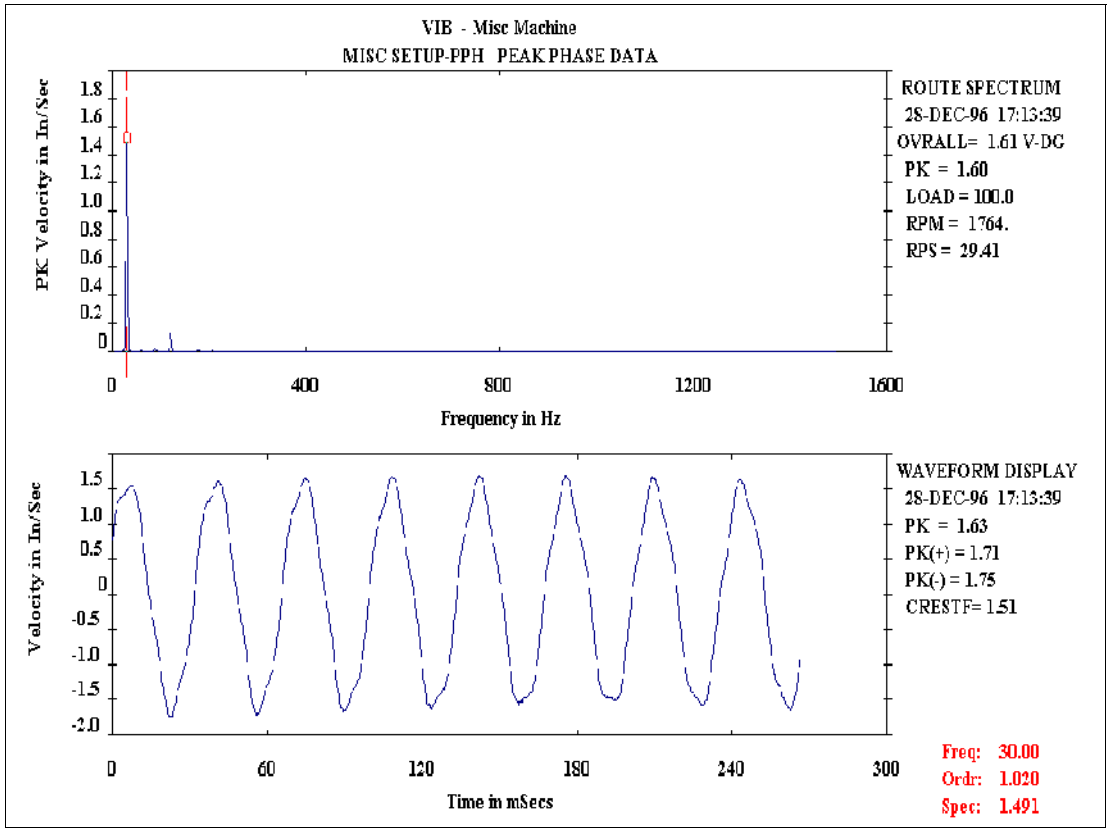
Velocity waveforms are useful for analyzing unbalance, misalignment, rubs and other low frequency problems.



The combination of the 2120 setting for signal integration mode and the route database settings of sensor type determine the final time waveform units type.

If the analyzer configuration for signal integration mode has been changed from the desired setting it will affect the time waveform data collected as part of a route.

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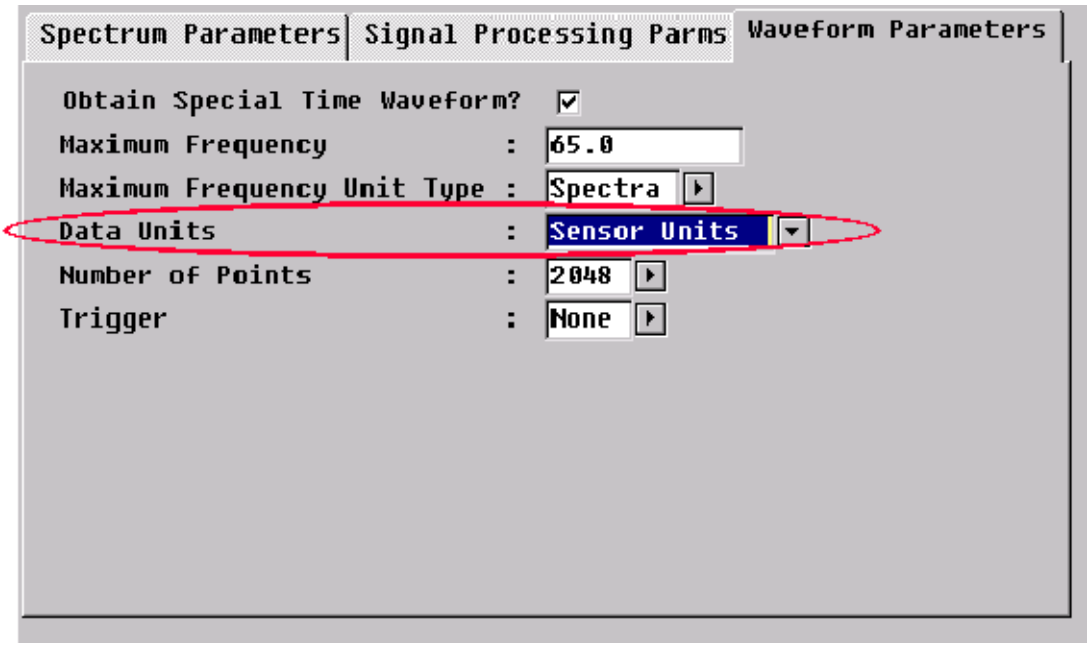
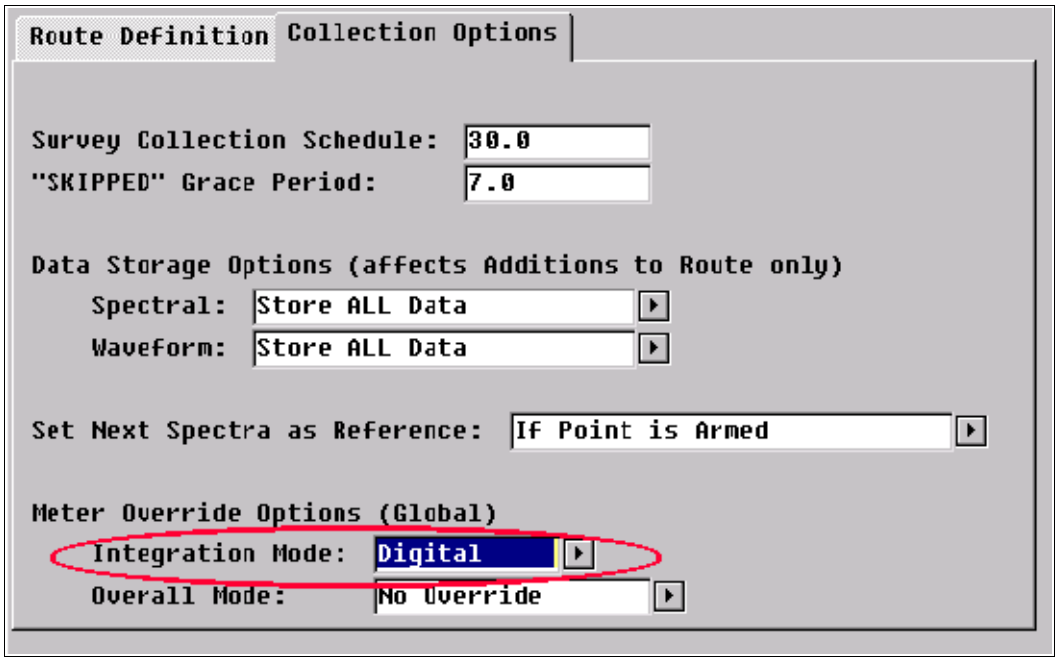
If using MasterTrend, remember to check this setting on the 2120 because it is not configured as part of a MasterTrend database unless:

- A special time waveform is specified in the parameter set



- The Route is configured to override the integration mode


Route Definition
Collection Options
Survey Collection Schedule: 30.0
"SKIPPED" Grace Period: 7.0
Data Storage Options (affects Additions to Route only)
Spectral: Store ALL Data
Waveform: Store ALL Data
Set Next Spectra as Reference: If Point is Armed
Meter Override Options (Global)
Integration Mode: Digital
Overall Mode: No Override

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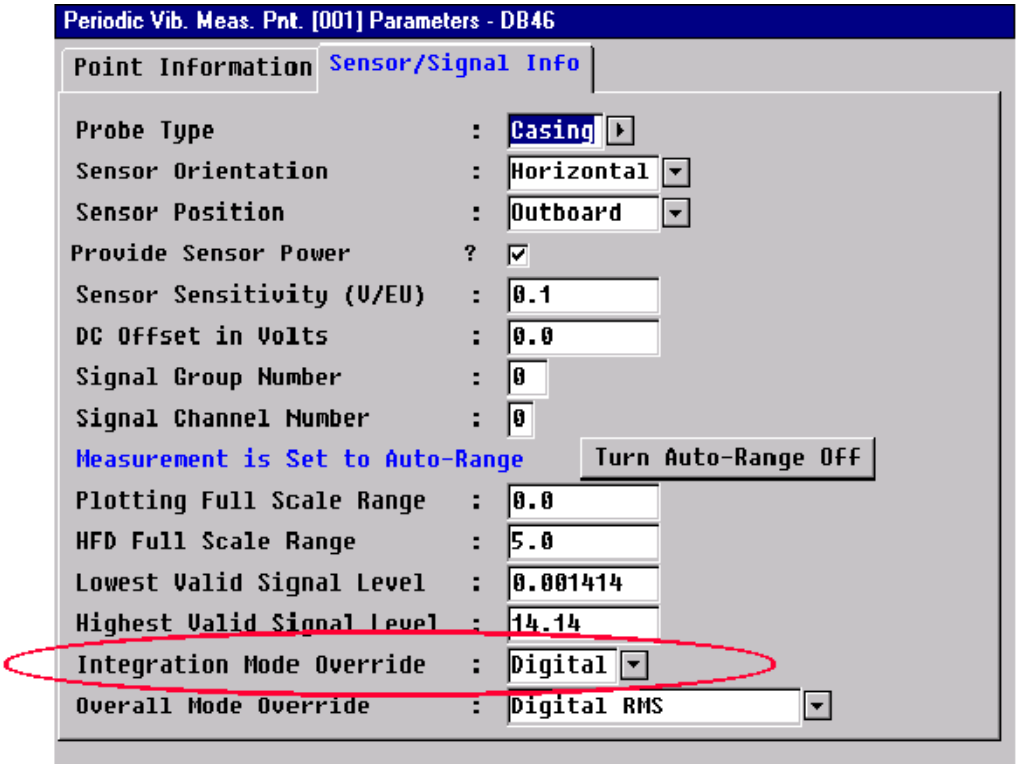
If using RBMware, the signal integration mode setting is configured from the point set-up screen.


Periodic Vib. Meas. Pnt. [001] Parameters - DB46
Point Information
Sensor/Signal Info
Probe Type : Casing
Sensor Orientation : Horizontal
Sensor Position : Outboard
Provide Sensor Power ? ✓
Sensor Sensitivity (V/EU) : 0.1
DC Offset in Volts : 0.0
Signal Group Number : 0
Signal Channel Number : 0
Measurement is Set to Auto-Range
Turn Auto-Range Off
Plotting Full Scale Range : 0.0
HFD Full Scale Range : 5.0
Lowest Valid Signal Level : 0.001414
Highest Valid Signal Level : 14.14
Integration Mode Override : Digital
Overall Mode Override : Digital RMS

If none of these programming features are utilized, the analyzer will collect waveform units based on the signal integration setting in the Utility menu and the Units type code in the point set-up screen of MasterTrend or RBMware.

Analog integration gives the best analyzer performance at low frequencies. An SST measurement requires analog integration for best results.

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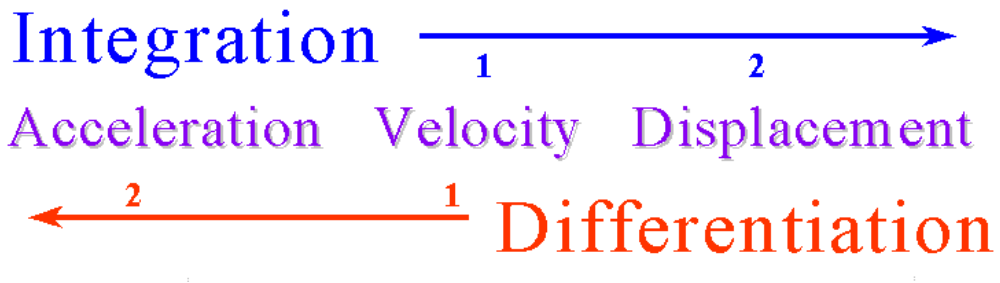
Software Integration and Diffentiation

The conversion of spectral data in MasterTrend and RBMware from acceleration to velocity or displacement one measure to another is called software integration or differentiation. The time waveform can only be converted in RBMware.



The diagram shown above illustrates the following examples:

- If an accelerometer is used and the signal is integrated once, the result is Velocity. If the accelerometer signal is double integrated, the result is Displacement.
- If a velocity sensor is used and the signal is integrated once, the result is displacement.
- If a displacement sensor is used and the signal is differentiated once, the result is Velocity. If the signal is double integrated, the result is acceleration.
- If a velocity sensor is used and the signal is differentiated once, the result is acceleration.

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The chart below is another way of illustrating integration and differentiation of signals.

	Acceleration	Velocitiy	Displacement
Single Integration	Velocity	Displacement	na
Double Integration	Displacement	na	na
Single Differentiation	na	Acceleration	Velocity
Double Differentiation	na	na	Acceleration

What do Displacement, Velocity, and Acceleration represent?

D (Displacement) = distance traveled by vibrating object

V (Velocity) = change in Displacement/change in Time

A (Acceleration) = change in Velocity/change in Time

Displacement is a measure of Stress and Motion. Velocity is a measure of Fatigue and Energy. Acceleration is a measure of Force.

How are these unit types related mathematically? They are often represented with the following equations:

$$D = X$$

$$V = X / T$$

$$A = X / T / T = V / T$$

Therefore, if any one of these terms has been measured, integration and differentiation allow any of the other terms to be calculated, provided the analyzer or software used is capable of this conversion process. CSI analyzers allow conversion of Time and Frequency domain data in the set-up pages of Analyze/ Monitor, Analyze Acquire, Off Route and in the applicable DLP programs. MasterTrend and RBMware allow conversion of stored spectral data between unit types and also configure data collection modes.

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One drawback to integration is a flare-up of the lower frequency data caused by the integration process. This effect is often called *integration* noise or a *ski-slope* effect. This is very noticeable when integrating from acceleration to velocity or acceleration to displacement. This may cause the overall vibration level to be higher than usual if not excluded from the calculation of the overall vibration level.

Summary

This section has introduced some signal processing basics. A clear understanding of signal processing may help the analyst when making decisions on how to setup a vibration data collection point. PeakVue is a unique process, with great power in many applications. We will examine PeakVue in greater detail in the next section.

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PeakVue

Section 3

Objectives

- Learn to use PeakVue Processing.
- Acquire a basic understanding of PeakVue processing.

CSi means Reliability Training

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Introduction

Detection of bearing and gear faults is one of the primary expectations of a predictive vibration program. An analyst will spend much of his/her analysis time looking at the data for early signs of bearing and gear wear. Analysis parameters are helpful tools for finding faults, however, the effectiveness of "normal' bearing and gear analysis parameters may be compromised by other, fault vibrations.

In a normal spectrum and waveform, the earliest signs of a bearing fault will be observed in the 2,000 – 5,000 Hertz area of the spectrum.

Point 1: If an analysis parameter band is configured to trend energy in this area of the spectrum, it may also include energy from other defects like electric motor faults or resonances.

Point 2: A high F_{max}, like 5000 Hertz, may be undesirable because it increases the measurement bandwidth and pushes the operational vibrations to the left edge of the spectrum.

Point 3: The waveform of an early stage bearing defect might show tremendous acceleration levels and a spectrum with broadband noise but no specific defect frequencies. This kind of information is very difficult, if not impossible, to interpret. On a machine that has both rolling element bearings and gears, a comprehensive analysis may not be possible.

Point 4: Slow speed shafts make bearing analysis more difficult.

What is the solution? How can an analyst save a significant amount of analysis time looking for early signs of bearing and gear wear? The answer is to utilize PEAKVUE as a measurement tool.

This section describes PeakVue processing. PeakVue is proving to be the preferred technique for detection of bearing and gear defects. PeakVue processing has been effective in both slow speed and high speed applications. PeakVue is able to detect bearing and gear faults far earlier than normal signal collection methods.

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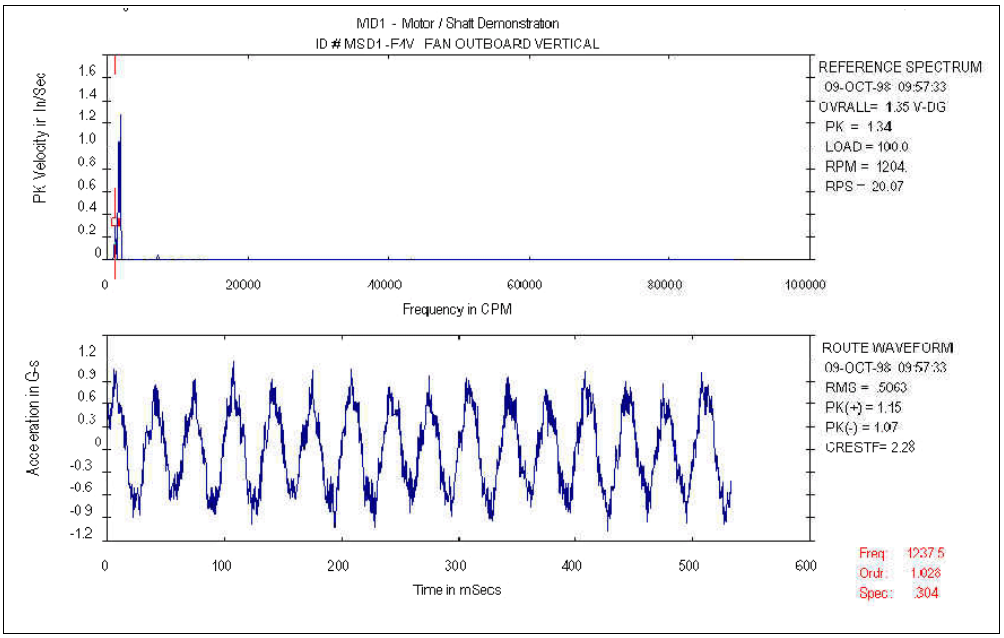
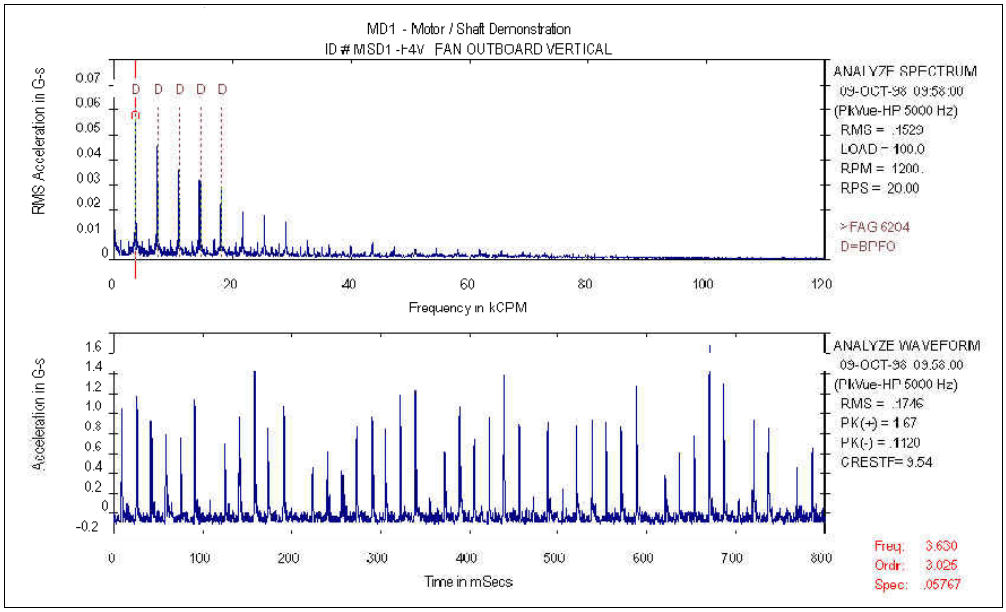
The plots below show a normal spectrum and waveform. Nothing in the spectrum or waveform is indicating a bearing fault.

NORMAL SPECTRUM



The plots below show a PeakVue spectrum and waveform. The spiking in the waveform is unmistakable. The spectrum shows a BPFO fault.

PeakVue Spectrum



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PeakVue

PeakVue stands for **P**eak **V**alue. PeakVue analysis is actually a measure of "stress wave" activity in a metallic component. Stress waves are associated with impact, friction, fatigue cracking, lubrication, etc., and generate faults in various components such as rolling element bearings and gears. For example, when a rolling element impacts a defect on a bearing raceway, it will generate a series of stress waves that propagate away from the location of the defect in numerous directions. The wave propagation introduces a ripple on the machine surface that introduces a response output in a sensor detecting absolute motion such as an accelerometer or a strain gage.

PeakVue is a new technique for measuring stress waves. PeakVue captures and holds the peak value of the time waveform and utilizes filters to pre-process the vibration signal. PeakVue is a standard feature of the CSI 2120 Signal Analyzer. PeakVue is extremely well suited for the early detection of bearing and gear faults. It is a powerful complementary tool that can detect a range of faults and problem conditions that techniques such as Vibration Analysis alone might miss under certain conditions.

Some common defects which generate stress waves are pitting in antifriction bearing races causing the rollers to impact, fatigue cracking in bearing raceways or gear teeth (generally at the root), scuffing or scoring on gear teeth, cracked or broken gear teeth and others. The challenge becomes one of detecting and quantifying the stress wave activity relative to energy and repetition rate. This leads to the identification of certain faults and, with experience, allows evaluating severity of those faults detected.

Stress wave emissions are short-term transient events lasting several microseconds to a few milliseconds. The waves propagate away from the initiation site as bending(s) and longitudinal (p) waves at the speed of sound in metal. The stress waves introduce a ripple on the surface which will excite an absolute motion sensor such as an accelerometer. A smaller impacting object excites a shorter wavelength, and therefore, generates a higher stress wave frequency. A larger impacting object excites a longer wavelength, and therefore, generates a lower stress wave frequency. The detection and classification of these stress wave packets provides an important diagnostic tool for (a) detecting certain classes of problems and (b) severity assessment.

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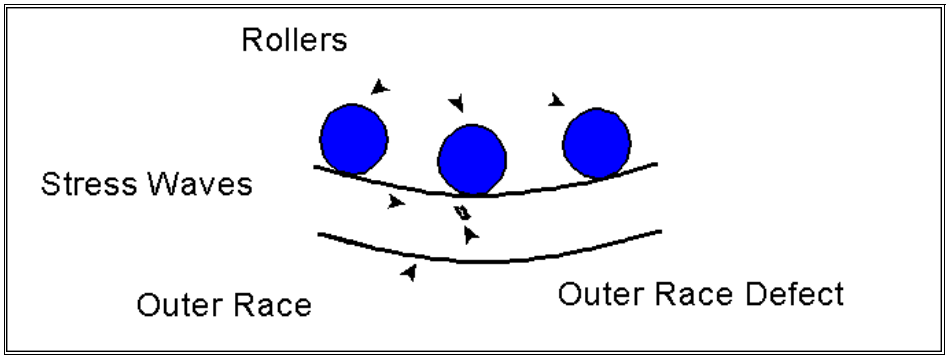
Stress Waves have the following characteristics:

1. Short term transient events - microseconds to a few milliseconds in duration
2. High frequency - generally concentrated from 1kHz to 15 kHz



The frequencies generated by the stress waves are predominantly controlled by the ratio of the speed of sound within the media over the wavelength. Frequencies are largely concentrated in the 1000 to 15,000 Hz range (largely dependent on the mass and geometry of the impacting object, the type of surface it impacts, etc. Stress wave frequencies can extend up to 50,000 Hertz. Stress waves also excite and include frequencies excited by system resonances. However, it is surprising that the contribution of such resonant responses is typically only 5% to 10% of total stress wave content.

For an accelerometer at a fixed location, the wave propagation will be a reasonable short-term transient event lasting on the order of microseconds to a few milliseconds. The duration of the event will be dependent upon:

1. Type of event (e.g., stress waves from impacting will last longer than stress waves accompanying the release of residual stress buildup through fatigue cracking)
2. Relative location of the sensor (accelerometer) to the initiation site
3. Severity of the fault responsible for the stress wave emission

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Sensor Selection and Location

Due to the rapid dispersion of stress waves, it is desirable to locate the sensor as near to the stress wave origin as possible. This generally will be in the load zone on the bearing housing. Stress waves will propagate in all directions. Hence the selection of axial, vertical, or radial is less of an issue than is mounting the sensor in or near the load zone.

The bending stress waves introduce a ripple. Any sensor which is sensitive to absolute motion occurring at a high rate would suffice, providing it has sufficient frequency range and amplitude resolution capabilities. Therefore, this sensor could be an accelerometer with sufficient bandwidth, an ultrasonic sensor, a strain gauge, piezoelectric film, et al.

The primary purpose of stress wave monitoring is to acquire periodic measurements used to determine machine health. The sensor of choice for stress wave monitoring is the accelerometer – probably the same accelerometer used for normal vibration measurements. The requirements for this sensor include sufficient analysis bandwidth (frequency range), amplitude resolution and appropriate sensitivity.

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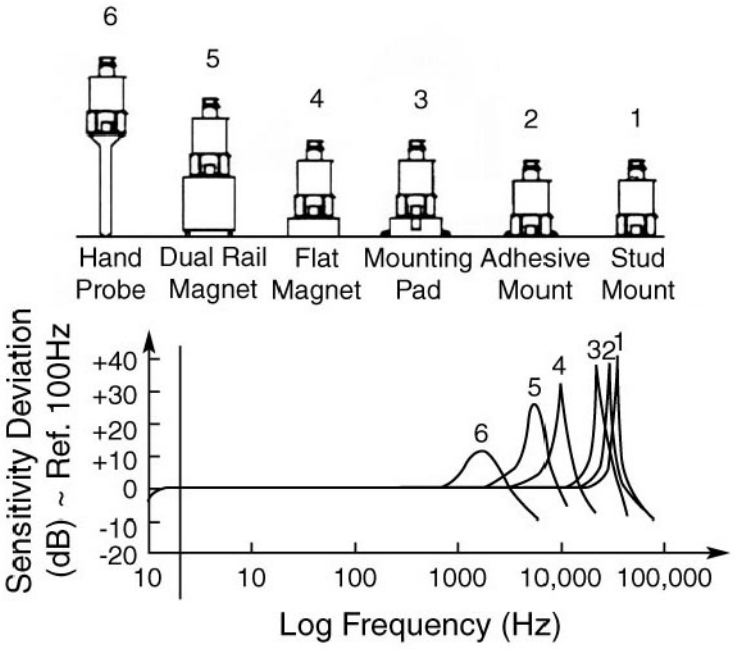
The bandwidth of an accelerometer is dependent on (1) its design and (2) the manner in which the accelerometer is attached to the surface. The general effect, which different mounting schemes have on the sensor bandwidth, are presented in the figure below (sensor becomes entire system attached to the surface).



Typically, a standard 100 mv/g accelerometers is used for most PeakVue measurements – even on low speed machines since the PeakVue information will still typically be above 500 Hz (30,000 CPM). There are special cases where either a higher sensitivity or lower sensitivity accelerometer might be needed to improve PeakVue measurements. For example, if the machine is at very low speeds lower than 5 to 10 RPM (certain 500 and 1000 mv/g accelerometers now have the ability of making low frequency vibration and higher frequency measurements required to detect PeakVue information). On the other hand, if a machine generates very high frequencies (above 10,000 to 20,000 Hz or greater) a special 10 mv/g, high frequency accelerometer may improve the information detected by PeakVue.

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PeakVue's ability to detect various fault types is determined by both the transducer mounting surface and the mounting method. The variations that exist in each application can limit the F_{MAX} and high-pass filter that can be used in a PeakVue measurement (painted versus unpainted surface; flat versus curved surface, smooth versus rough surfaces, etc.).

A 2-pole magnet, has been found to be useful for stress wave detection in some applications, with the precaution that the magnet must be placed on a clean, smooth surface. Painted surfaces should be avoided. Thick paint filters out stress waves. There should be a minimum of dual line contact made between the magnet rails and the curved surface of the machine. Limitations on using this mounting scheme will be addressed later in this chapter.

A flat, rare earth magnet will capture more meaningful PeakVue data than will a 2-pole magnet if mounted on a flat, reasonably clean surface. This is particularly true when a frequency bandwidth (F_{max}) greater than approximately 3000 Hz (180,000 CPM) is needed, or if a high-pass filter greater than 2000 Hz is used. Tests have shown that if either of these two conditions exists, fault frequencies above approximately 3000 Hz which are detected by a flat rare earth magnet, can be missed altogether by a 2-pole magnet when making PeakVue measurements. Use of the hand-held probe is not recommended.

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PeakVue Processing

The analog output of an accelerometer, mounted on a machine, includes normal vibration signals and stress wave energy over the entire response bandwidth of the sensor system. The normal vibration portion of the signal consists of lower frequencies and the stress wave portion consists of high frequencies.

For **normal vibration** measurements, the normal component is separated from the stress wave activity by routing the analog signal through a high order, low-pass filter followed by the conversion to the digital domain. The sampling rate is 2.56 x F_{max}.

For **PeakVue** measurements, the stress wave component of the signal is separated form the normal vibration by routing the signal through a high order high-pass analog filter. Prior to routine digitization of the resultant signal for further analysis, the high frequency signal is further processed.

The important parameters to capture from stress wave activity are:

- Amplitude of each event
- Approximate time required for the detected event to occur
- Rate (periodic or non-periodic) at which events are occurring with emphasis on event rate versus specific fault frequencies which are dependent on both the specific component and on machine rotational speed.

The method developed by CSI that captures peak values of the analog signal from the sensor post-passing through the high-pass filter, called PeakVue, provides the three key parameters specified above. The appropriate time resolution is accomplished by the selection of the maximum frequency, F_{max}, to obtain adequate resolutions of possible fault frequencies, e.g., an F_{max} of 3 or 4 times the inner race fault frequency when monitoring bearings. Once the F_{max} is specified, peak values will be collected at a rate of 2.56*F_{max}. The inverse of the sampling rate defines the time increment over which the peak value is captured.

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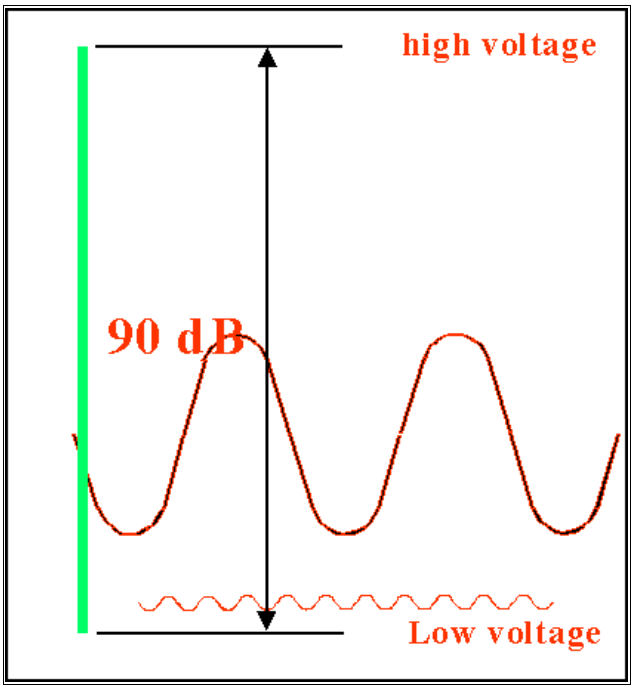
These peak values are captured sequentially until the total desired block length is accumulated. The total time in the PeakVue waveform depends on the number of shaft revolutions desired by the analyst and the block of data consists of sequential constant time intervals of peak values (the PeakVue spectrum is computed from the time block data by an FFT algorithm as are vibration spectra). For bearing fault analysis, the block time should be sufficient to provide adequate resolution on the lowest fault frequency (cage fault). This suggests a minimum of 15 revs (preferably 20) be included in the captured peak value data block.

Dynamic Range

Dynamic range is defined as the ability of the analyzer to distinguish between the highest and lowest amplitude signals. It is controlled by the Analog to Digital (A/D) processor.



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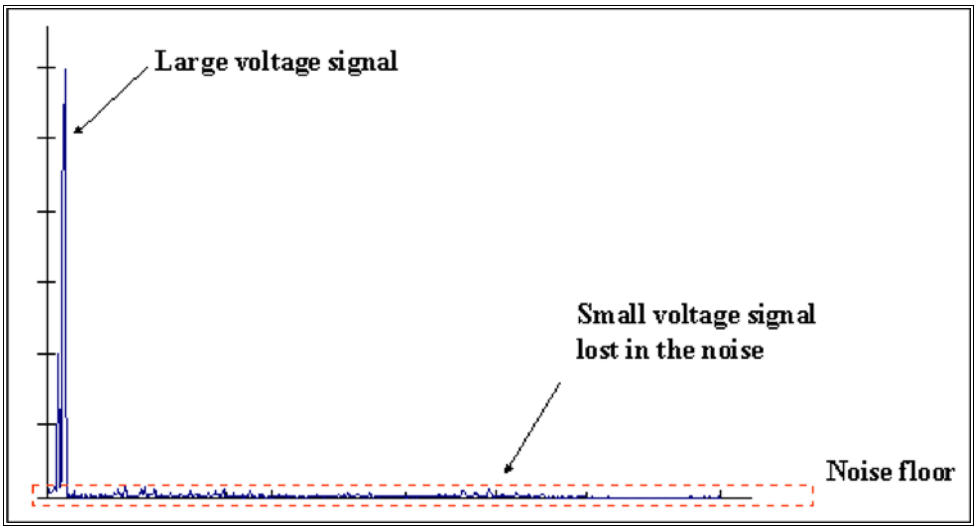
The 2120 has a greater than 90 dB dynamic range. If two vibration frequencies have amplitudes greater than 90 dB apart, the lower amplitude signal will not be visible in the spectrum. It will be "lost in the noise". Put another way, the lower amplitude signal will be lower than the noise floor of the analyzer.



Low amplitude stress wave energy is particularly difficult to resolve when the signal is dominated by unbalance, misalignment and other low frequency vibrations. Filtering out the non stress wave energy assures stress wave signals are measured with good signal to noise ratio.

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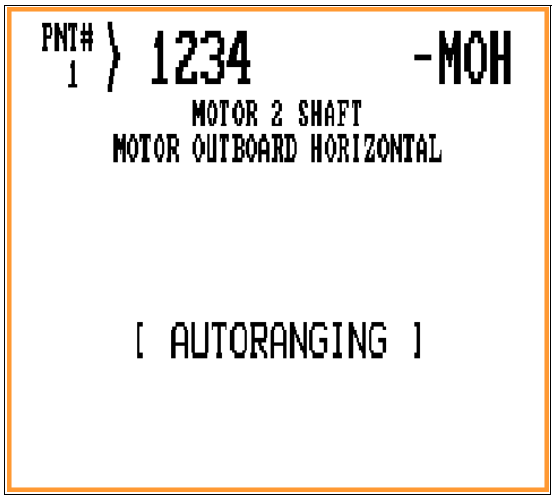
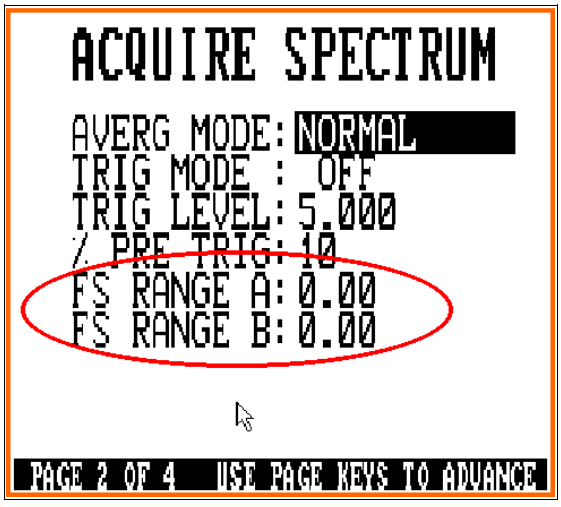
Auto-ranging

The **AUTORANGE** function of the 2120 analyzer selects a signal input range based on the incoming voltage signal. The Autorange feature optimizes the dynamic range of the 2120 analyzer. The autorange function is typically always enabled when measuring periodic signals. When the Enter button is pressed on the 2120 analyzer, AUTO-RANGING is the first thing seen on the screen.



The F.S. Range function can be disabled on the 2120 analyzer itself if acquiring data in the ANALYZE or OFFROUTE modes or through a route point configuration defined in MasterTrend or RBMware. A F.S. Range value of ZERO (0) instructs the analyzer to autorange. Any number, other than zero, in the F.S. range field forces the analyzer's input buffer to be fixed to a specific vibration level. The number entered into the F.S. range is always in waveform units.


ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : OFF
TRIG LEVEL: 5.000
% PRE TRIG: 10
FS RANGE A: 0.00
FS RANGE B: 0.00
PAGE 2 OF 4 USE PAGE KEYS TO ADVANCE

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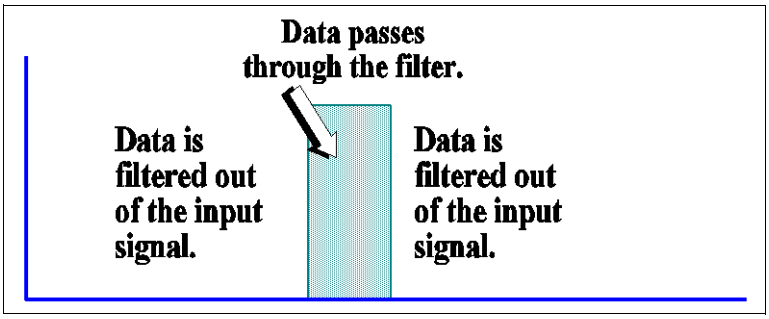
PeakVue Filter Types

PeakVue uses of two types of filters: **Band Pass** and **High Pass**.

The purpose of filtering the signal is to remove non-stress wave energy that typically constitutes much of the signal's amplitude. By removing the non stress wave signals, the 2120's entire 90 db of dynamic range is focused on resolving the stress wave energy.

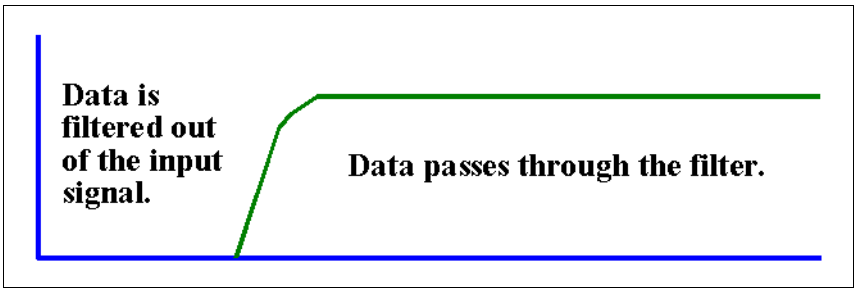
Band-Pass Filter

The bandpass filter removes all data above and below the filter corner values.



High-Pass Filter

The high-pass filter removes low-frequency vibrations. All data below the filter value are removed from the signal. Selection of the high pass filter frequency filter is the most important consideration when using PeakVue. The goal of the filtering process is to remove the rotational vibration frequencies such as turning speed harmonics, bearing frequencies, multiples of gear mesh frequency, etc. The high pass filter should be selected to remove these rotational frequencies. Select a filter above the highest operational or defect frequency present in the signal. Generally, the 1000-Hz high pass filter is a good choice.



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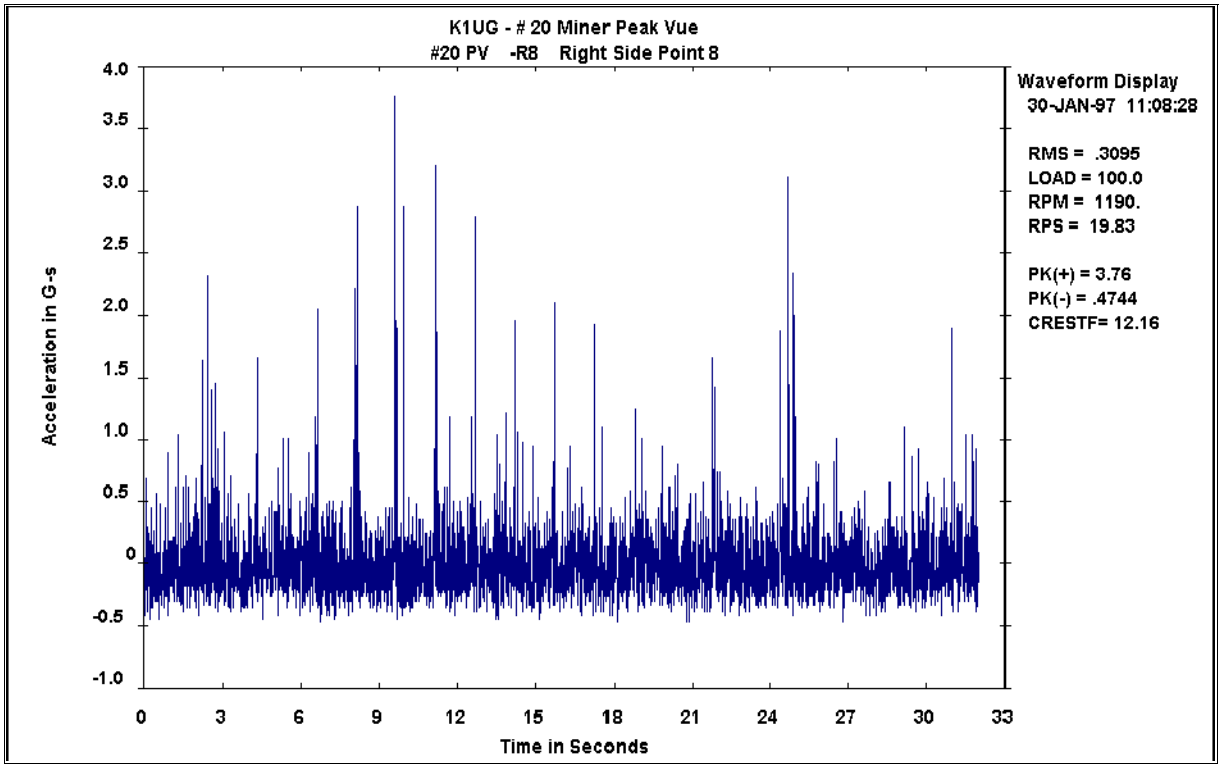
Rectified Signal



Only the top half of the waveform is shown in the final PeakVue waveform.

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Recommended PeakVue Data Acquisition Parameters

When setting up for a PeakVue measurement, the analyst must determine the analysis **Bandwidth** (F_{max}), the **Resolution** or number of lines, the averaging type and number of **Averages**, the optimum **High-pass filter** to be employed (or band pass filter in special curcumstances), as well as the sensor (and mounting) to be used.

ALWAYS collect PeakVue spectrums and waveforms in ACCELERATION using an accelerometer.

PeakVue Analysis Bandwidth (F_{max})

The maximum frequency span is determined by the highest expected fault frequency (also referred to as "highest forcing frequency"). In the absence of gear meshing, the inner race (BPFI) fault frequency is the highest frequency for rolling element bearings. The F_{max}, should be set greater than 3 times BPFI (preferably 4 X BPFI).

The primary factors that influence the data acquisition parameter set, including the F_{max}, are machine speed and the type of fault for which detection is desired. As an example, consider a machine having rolling element bearings as the primary source for faults. The highest fault frequency will be the inner race. The number of rollers can cover a large range, but a large number of commonly used bearings will have less than 18 rollers. Hence the inner race fault will typically be less than 12 times running speed. It is desirable to have a minimum of three harmonics of this fault frequency within the analysis bandwidth; therefore an analysis bandwidth (F_{MAX}) of 40 orders would be a reasonable generic setup for a machine outfitted with rolling element bearings.

For gear mesh faults, the analysis bandwidth, Fmax, should be set greater than two times gear mesh (preferably greater than three times gear mesh if 3 X GMF does not exceed 2000 Hz). If both 2.25X GMF and 3.25X GMF exceed 2000 Hz, it will be necessary to use the 5000 Hz High-Pass Filter, but special precautions pertaining to the mounting surface, mounting shape and cleanliness will demand close attention if a 5000 Hz High-Pass Filter is employed.

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If there are multiple shafts within the gearbox, then a measurement point should be located on each bearing. The Fmax should be greater than twice times the highest gear mesh for the set of gears on that shaft (preferably at 2.25 X Highest GMF). However, it is important that the same high-pass filter is specified for all measurement locations at each point on a gearbox (high-pass should be set greater than or equal to 2.25 X Highest GMF); then, Fmax can be changed at each point and should be optimized for each particular location using the information covered in this section (one Fmax may have to be used for evaluating bearings, misalignment, eccentricity, etc., and a higher Fmax used for evaluating the gears).

Lines of Resolution and Number of Time Domain Samples

After selecting the high-pass filter and bandwidth for data acquisition, the next parameter to be selected is the frequency resolution. The resolution is set by specifying the number of lines, e.g., 400, 800, 1600, etc. The controlling criterion is to provide sufficient resolution to resolve the lowest possible fault frequency. For rolling element bearings, the lowest fault frequency is the cage frequency (FTF) which is in the proximity of 0.4 times shaft speed (i.e., the cage will complete one revolution for approximately every 2.5 revolutions of the shaft). It is important to have sufficient resolution to clearly resolve the cage frequency. This translates into having a time block of data capture 15-20 revolutions.

As a minimum, the time block of data must include six periods for the fault frequency to be resolved. Thus, to ensure that the cage frequency is displayed in the PeakVue spectrum, a minimum of 6 times 2.5 or 15 revolutions of the shaft speed must be included within the time block of data (preference is 20 revolutions of the shaft speed).

A convenient formula for computing the number of shaft revolutions contained within a time block of data is:

$$\#\ of\ Shaft\ Revolutions = \frac{No.\ of\ Lines}{Fmax\ (in\ orders)}$$

As an example, using an F_{max} of 40 orders, a 800 line analysis would have 20 revs within the time block of data; 1600 line analysis would have 40 revs., etc.

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When the operating speed exceeds 4000 RPM, 1600 lines are recommended. In addition, if PeakVue data is taken on a gearbox, it is generally recommended to capture a minimum of 1600 FFT lines (corresponding to 4096 time samples).

Number of Averages

Averaging is strictly an exercise to improve signal-to-noise in the spectral data only, i.e., the time block of data is the final block used for the spectral calculation (analyzers only store the final time block captured, no matter how many averages have been requested for the spectrum unless synchronous time averaging using a trigger is invoked).

In **normal vibration** measurements, it is most always a good idea to use multiple averages in order to improve the signal-to-noise ratio in the spectrum. Improving the signal-to-noise ratio will enhance the appearance of true periodic frequencies while suppressing random, non-periodic components normally associated with "noise". In general, spectral noise varies with the square root of the number of averages. That is, if the user increases the number of averages from 4 to 16 averages (4X), this should reduce spectral noise by 50%. Again, increasing the number of averages will not affect the vibration waveform whatsoever since only the final time block is retained.

Surprisingly, in **PeakVue**, it is not a good idea to acquire more than one time block. Hence only one average is recommended in PeakVue measurements. The primary reason for this is that the PeakVue time waveform has equal importance to the PeakVue spectrum. Therefore, it is better to spend the extra time that would be required for averaging to increasing the resolution by increasing the number of lines instead.

A much better result in reducing PeakVue spectral noise content can be achieved by increasing the number of FFT lines during PeakVue measurements. In fact spectral noise elimination varies directly with the number of lines. For example, if the user increases the number of lines from 800 to 1600 lines, PeakVue spectral noise should decrease by 50%.

Use one average for PeakVue measurements.

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Selection of Filters

In PeakVue, a finite number of band pass and high-pass filters are available from which to select. The choices currently available are presented below. The filter selection is dependent on the analysis bandwidth (F_{max}); and the frequency region where dominant energy is expected from the stress wave events due to potential faults that might be present. These are the Band Pass and High-pass filters that are currently available in the CSI 2120 and CSI 2120A analyzers.

PeakVue Filters	
Band Pass	**High Pass**
20 - 150 Hz	500 Hz
50 - 300 Hz	1000 Hz
100 - 600 Hz	2000 Hz
500 - 1000 Hz	5000 Hz
	10,000 Hz
	20,000 Hz

Special precautions must be taken when mounting the sensor if using a filter at or above 5000 Hertz (i.e., clean surface with no paint; flat rare earth magnet for 5000 to 10,000 Hz measurements; stud or adhesive mount for measurements above 10,000 Hz, etc.). Failure to take these precautions will likely result in loss of detection of fault frequencies in both PeakVue time waveform and spectral data.

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Choosing a High Pass Filter

For selection of a high-pass filter, the corner frequency must be greater than or equal to the F_{max} set for that measurement point (if the user specifies a lower value, the firmware within the instrument will increase the filter setting to the next available filter). If there are multiple measurement points located on a single metallic enclosure (machine), e.g., a gearbox, then the analyst should ensure that all measurement points located on the machine use the same high-pass filter setting established for the highest analysis bandwidth (highest F_{max}). In gearboxes, if the calculation of 2.25 X Highest Gear Mesh calls for a high-pass filter falling between two of the available choices, the user should choose the next higher filter, not the closest filter to this calculated value (i.e., if the calculation calls for a high-pass of 1100 Hz, the user should choose 2000 Hz, not 1000 Hz.

Choosing Band Pass filters

There are times when it is more appropriate to select band pass filters. One such event occurs on paper machines (as well as on press machines). This occurs when a felt develops certain classes of flaws which cause the felt to impact the rolls. Felt is constructed of a soft material. Thus, when a felt impacts a hard material, it excites much lower frequencies than does impact of hard material on hard material.

One application for selecting a band pass filter over a high-pass filter is when structural resonances (or other system natural frequencies) could possibly be excited by an impacting event which occurs at a slow rate but is periodic (a defective felt is a text book example). A less obvious case is when monitoring for bearing faults on a gearbox that has rolling elements of reasonable size (greater than 0.5"D), along with gear mesh frequencies within the system.

To illustrate, consider a certain gearbox driven by a gas turbine with the objective of generating power. The input gear mesh was about 10 kHz. A lower gear mesh in the gearbox was about 3.7 kHz. The objective was to detect a certain bearing with faults. If we follow the rules regarding selection of the high-pass filter, and select from the available filters, a 20 kHz high-pass filter would be used. The problem is we would be attempting to detect possible impacts from gears having significantly attenuated energy at frequencies greater than 20 kHz.

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The solution is to select a band pass filter which is sensitive to energy in a frequency band excluding gear mesh and two times gear mesh. The approximate 3.7 kHz gear mesh is the one closest to the region we expect most energy from impacting rollers. Thus a band pass filter was selected with a bandwidth of 5 kHz to 6.5 kHz (see Table II).

Other special applications may benefit from different band pass filters.

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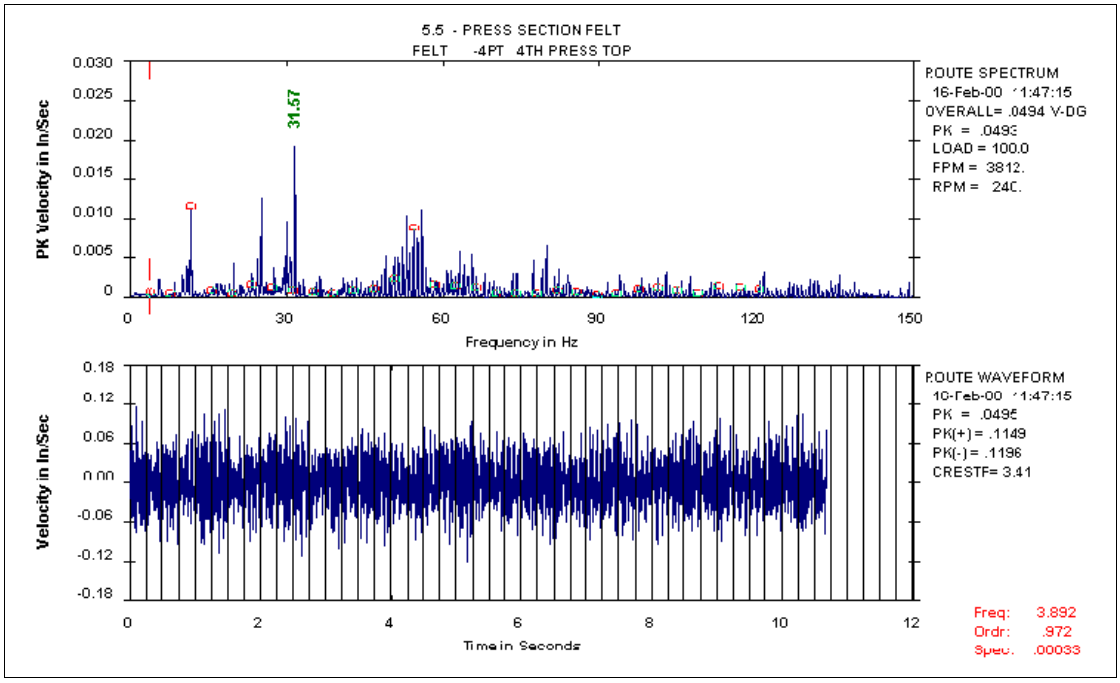
Case Study: Defective Felt on a Paper Machine

The (normal) velocity spectral data acquired on press roller are presented below. The activity in the vicinity of 50 - 60 Hz was noted to be greater than it had been. The velocity time waveform does not indicate any problem. The activity in the spectrum, especially in the 50 - 60 Hz range, does suggest periodic activity.

Normal Spectrum and Waveform



The auto-correlation coefficient function of the "normal" time waveform is shown below. Here, there are two periodic events occurring. The highest frequency event, the minimum lag time, is at 32 Hz (about 30% correlation) which is the dominant peak in the spectrum. The second has a period of 1.3 sec which corresponds to one event per 5+ revolutions of the roller. This longer period event could correspond to once per revolution of the felt.

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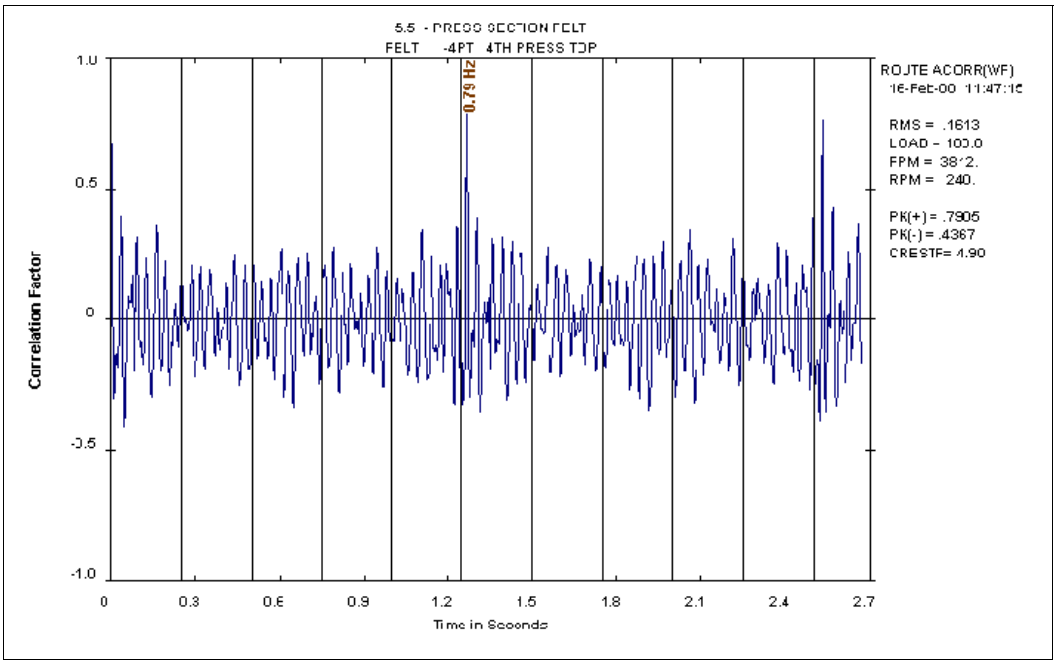
Auto-correlation Function



A PeakVue measurement was made. A felt impacting will most likely excite a structural resonance frequency. For press sections, this has been observed to typically be in the 50 - 150 Hz range. Thus a band pass filter was selected, which incorporates the suspected structural resonance. Two band-pass filters were tried: the 20 - 150 Hz and the 50 - 300 Hz filters.

The PeakVue plot of the 20 - 150 Hz band pass filter is shown below. The only activity of note in the spectral data is the 0.193 order (which is the felt turning speed) with many harmonics (where "first order" refers to 1 X Roll speed). The PeakVue time waveform does confirm the repetitive pattern of 0.193 orders but the auto-correlation coefficient function leaves no doubt of the impacting at the felt turning speed (note that 0.193 X RPM = 0.787 Hz = 47.2 CPM = 1 X Felt RPM). Note the clear impacts occurring at the rate of once per 5+ roll revolutions in the Auto-correlation coefficient function.

The obvious conclusion was that the felt had a minimum of one defective region. This was confirmed and the felt was replaced

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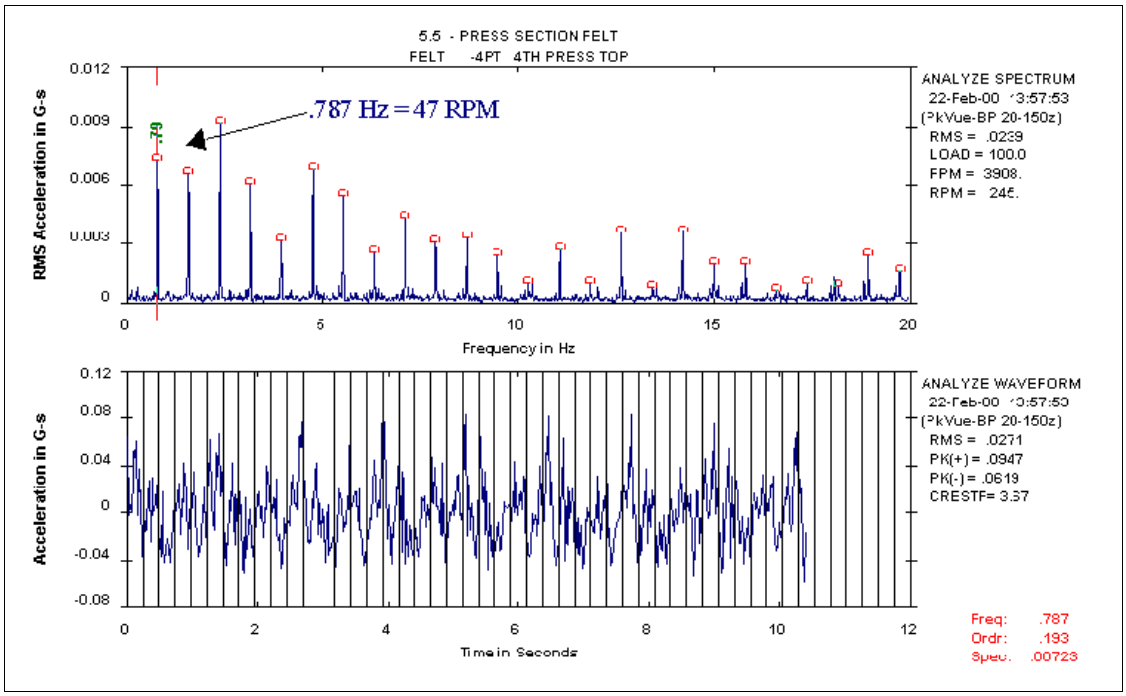
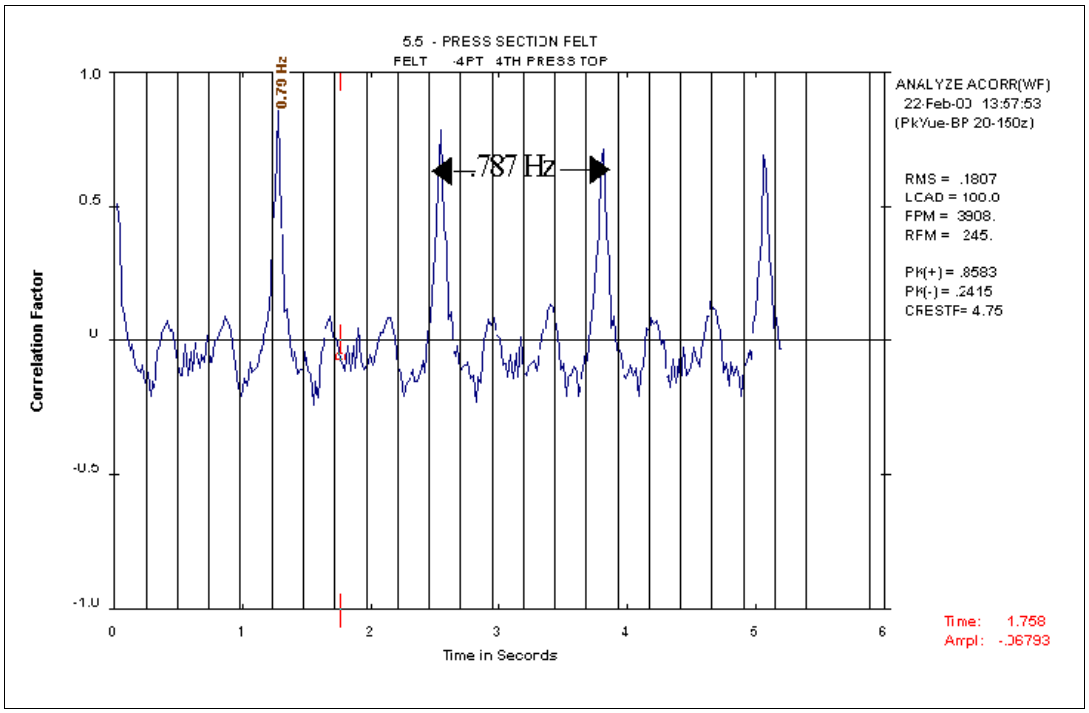
PeakVue Spectrum and Waveform



Auto-correlation function of PeakView Waveform



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PeakVue Acquisition Parameter Summary

The table below provides the recommended analysis bandwidth, $\mathbf{F_{max}}$, for machines running at various speeds. It likewise covers how F_{max} should be set up for both rolling element bearings and for gear sets. The table is intended to be a "Guide" when establishing PeakVue measurements in a condition monitoring database. Occasionally, the user will encounter special machinery or operating conditions that will mandate setting up such measurements somewhat differently. Examples of such special measurement situations include low-speed equipment such as the felt of a paper machine or on high-speed rotary screw or centrifugal air compressors. Studies to date indicate it might be better (in these cases) to employ band pass rather than high-pass filters.

PeakVue Setup Parameters for Detecting Rolling Element Bearing Faults

RPM	HI-PASS FILTER[6]	RECOMMENDED Fmax[3]		MAGNET	# AVGS	MIN. LINES
		KNOWN BEARING	UNKNOWN BEARING			
0-700	500 Hz	4xBPFI[2]	40xRPM[2]	2-Pole[5]	1	800
701-1500	1000 Hz	4xBPFI	40xRPM	2-Pole	1	800
1501-3000	2000 Hz	4xBPFI	40xRPM	Flat	1	1600
3001-4000	2000 Hz	4xBPFI	30xRPM	Flat	1	1600
4001-UP	5000 Hz[5]	4xBPFI	40xRPM	Flat	1	1600

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Table Notes:

1.····· This table was developed after conducting extensive research, laboratory trials and field tests (both within Condition Monitoring annual contract measurements and during diagnostic investigations). Use it as a guide when setting up databases (either in a Condition Monitoring program or on a Diagnostic project).

2.····· If using PeakVue measurements to detect **Gear Faults**, typically use 1600 Lines along with a High-Pass Filter exceeding about 2.25X GMF unless this frequency exceeds 2000 Hz (note that the optimum PeakVue High-Pass Filter would be specified at 3.25X GMF if this calculated frequency does not exceed 2000 Hz; if both 2.25X GMF and 3.25X GMF exceed 2000 Hz, it will be necessary to use the 5000 Hz High-Pass Filter, but special precautions pertaining to the mounting surface, mounting shape and cleanliness will demand close attention if a 5000 Hz High-Pass Filter is employed). However, if the 5000 Hz filter is chosen, the user must follow the guidelines of notes 4 and 5 below. These preparations will allow you to use a High-Pass Filter of 5000 Hz. If there are multiple shafts within the gearbox, then a measurement point should be located on each bearing and a high-pass filter used that is greater than twice times the highest gear mesh for the set of gears on that shaft (preferably at 2.25 X Highest GMF). Fmax can be changed at various points on the gearbox.

3.····· FMAX cannot exceed the High-Pass Filter (however, it is permissible for FMAX to equal the High-Pass Frequency).

4.····· Paint should be cleaned off mounting surface. In all cases, mounting surfaces should be clean and free of dirt/oil/foreign particles. Surface should be smooth. If more than one layer of paint is present, the paint can significantly dampen the resulting PeakVue signal.

5.····· Do not use a 2-Pole Magnet when using a High-Pass Filter above 2000 Hz. Doing so will result in loss of impact response data. Use a Flat Rare-Earth magnet mounted on a flat surface and insert a thin layer of grease, silicone or wax between the magnet and the mounting surface when using a High-Pass Filter of 5000 Hz or greater. Field tests have proven that if fault frequencies are present above approximately 3000 Hz, which are detected by a flat rare earth magnet, such frequencies can be missed altogether by use of a 2-pole magnet when making PeakVue measurements. (2-pole magnets are often referred to as "dual rail" magnets).

6.····· In most applications, PeakVue should be set up to use high-pass filters rather than band pass filters. This would include the great majority of rolling element bearing, gear and lubrication faults for machines typically operating at 300 to 3600 RPM.

Summary of PeakVue Measurement Rules

Keep in mind that PeakVue is a high frequency measurement – even on low speed equipment. The following are recommendations for making measurements.

- Use a 0.1 v/G accelerometer – make sure the accelerometer has a frequency response that is greater than 5,000 Hertz. A 500 mv/G accelerometer can be used in certain circumstances.
- Use a Rare Earth, flat magnet or stud mount (a 2 pole magnet is acceptable under certain circumstances). It is important to have a good solid transmission path between the bearing/gear and sensor.
- Flat, clean, metal to metal contact between accelerometer and machine being measured, no paint or dirt.

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- A coupling agent between metal interfaces (bees' wax or grease) improves the connection.
- Measure at least one position per bearing for early detection of defects.
- Measure in the load zone for best results.
- Select a F_{max} that shows the highest defect frequency plus several harmonics.
- Use enough lines of resolution to resolve the lowest frequency fault.
- Select a high pass filter above the highest defect frequency. The filter setting must be equal to or one step higher than the Fmax.
- Use analog or digital integration (analog for low frequency).
- Measure in acceleration (both waveform and spectrum).
- Use Hanning window function.
- Use Normal averaging with one average.
- Let the analyzer autorange the input signal.
- A tachometer is not required.

PeakVue can be set-up from MasterTrend or RBMware.

PeakVue can be accessed from various software and firmware programs.

PeakVue measurement points may be configured from both MasterTrend and RBMware

From the ANALYZE mode of the analyzer, PeakVue is configured from Acquire Spectrum, Monitor Waveform and Monitor Spectrum.

PeakVue points can be configured from the Offroute mode.

Both of the Advanced Downloadable programs offer PeakVue as a measurement option. The Advanced Transient DLP offers long digital time waveform collection of PeakVue data. The Advanced Two-channel DLP offers PeakVue in addition to the cross-channel functions.

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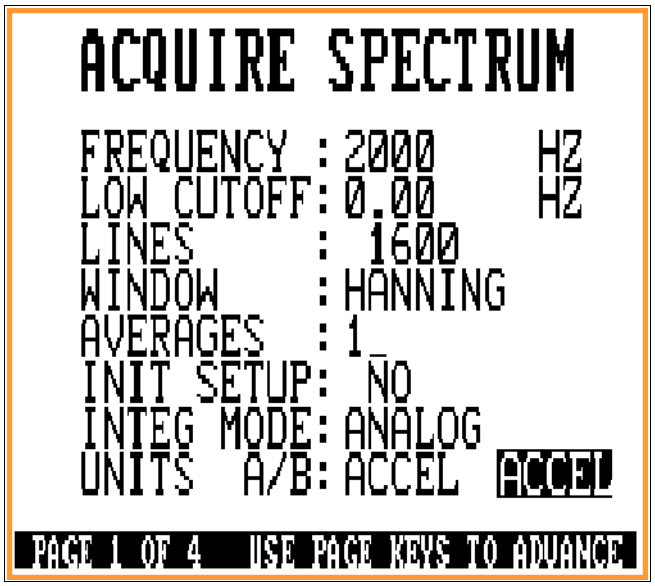
2120 Setup in ANALYZE / ACQUIRE Example

PeakVue is accessed from the 2120 Analyze/Acquire Spectrum Menu.



◆ **FREQUENCY**	Choose a F_{max} to see the highest defect frequency plus two or three harmonics
◆ **LOW CUTOFF**	Normally 0 (zero)
◆ **LINES**	Enough to resolve the lowest frequency fault
◆ **WINDOW**	Use Hanning for periodic data
◆ **AVERAGES**	Use one average
◆ **INIT SETUP**	Set to NO
◆ **INTEG MODE**	Analog or Digital - Use Analog for slow speed
◆ **UNITS MODE**	Acceleration - This keeps the units in G's. The integration mode has no effect because no integration is occurring (acceleration<-----acceleration.)

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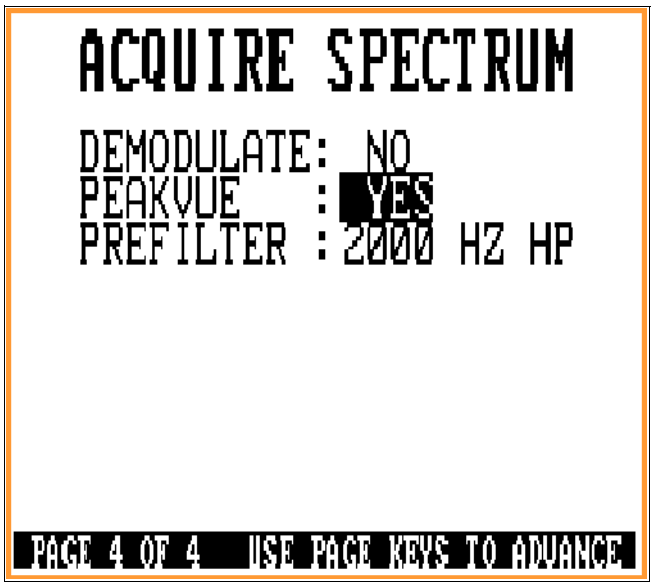
Page down to the fourth page of the setup menu to configure the PeakVue settings.



◆ **DEMODULATE**	Set to NO
◆ **PEAKVUE**	Set to YES
◆ **PREFILTER**	Select the appropriate filter
◆ **High-Pass Filter Selections**	500, 1000, 2000, 5000, 10000 and 20000 (Hz)
◆ **Band-Pass Filter Selections**	20-150, 50-300, 100-600, 500-1000 and 5000-6500

Collection of at least one PeakVue point per bearing is recommended. For machines that run at less than 300 RPM, PeakVue should begin to replace normal processing for all readings. The Slow Speed Technology function (SST) should be used when it is necessary to measure the turning speed and harmonics of low speed shafts. PeakVue is a better measurement choice for tracking bearing faults.

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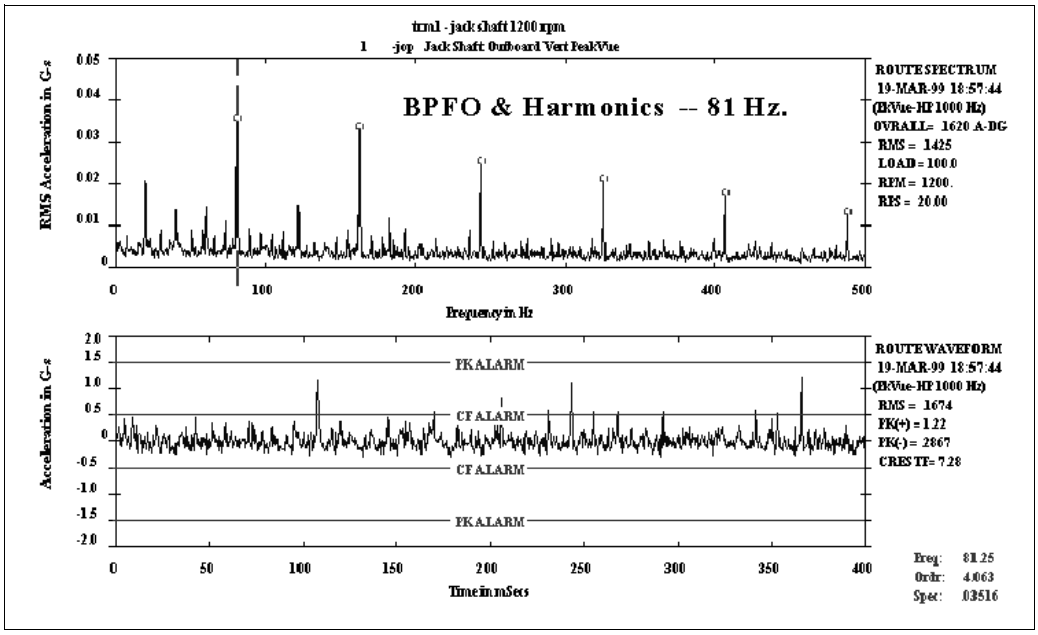
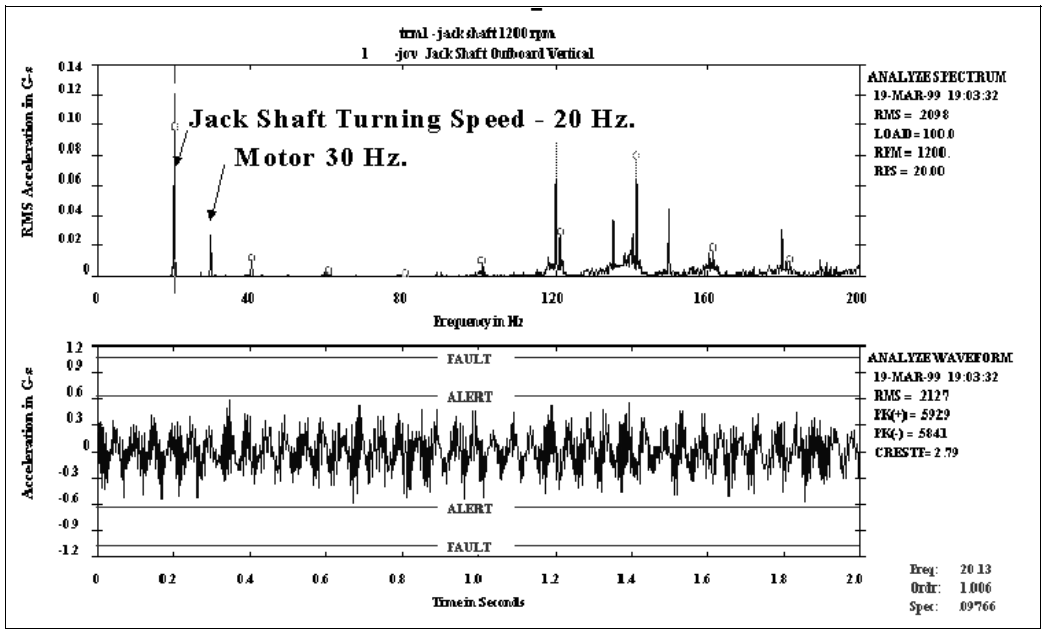
An example of PeakVue Power:

This measurement, made with PeakVue, shows very obvious signs of 81 Hertz and harmonics – an outer race bearing defect.



The following velocity waveform and spectrum show no signs of bearing defects at 81 Hertz. Both the spectrum and waveform are displayed in acceleration.



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Analysis of PeakVue data

Once a peak value time block of data is acquired, further analysis proceeds by:

1. Examination of the peak value time block of data looking at peak values incurred in a consistent pattern [the peak values are (a) trendable and (b) useful for severity assessment]
2. Analysis of peak value time block of data employing the auto correlation methodology. The primary capability of this analysis tool provides the extraction of a periodic signal from a signal consisting of significant non-periodic noise.
3. Analysis of PeakVue spectral data for correlation with known fault frequencies
4. Analysis of PeakVue parameter trends
5. Analysis of "normal" spectral data to see if bearing fault frequencies are visible are present at the calculated defect frequency.

The Time Waveform will have a band of energy centered around zero. If the waveform has no positive going peaks, then no defects exist and the spectrum will not show any peaks. It will only show an elevated baseline.

Defects exist if the Time Waveform shows positive going spikes (as in the example above). When waveform spikes are present, the spectrum will show peaks with harmonics for every defect. More severe defects will show more harmonics.

The amount of energy in PeakVue spectra and waveforms depends upon the severity of the defect, load at the measured position, transmissibility of the signal, quality and quantity of lubricant in the bearing and speed of the shaft.

Slow speed shafts produce less defect energy. Alarm limit values need to be learned through experience.

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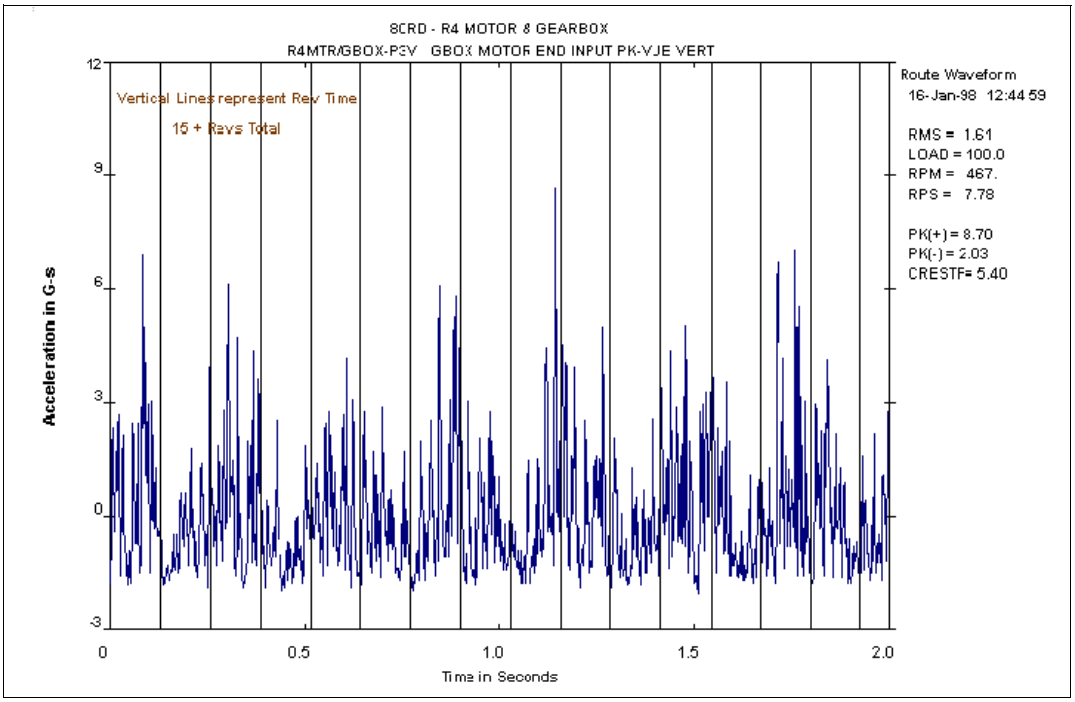
Although PeakVue data shows obvious signs of defects, the actual defect may be quite small and not require maintenance for some time. *Trend the defect using PeakVue parameters and watch normal vibration spectra for the defect to appear at the calculated defect frequency.* When the fault is visible in a normal spectrum, the bearing fault has progressed to the later stages of failure. Use the correlation between PeakVue and normal vibration data to determine when to repair.

Recommendations for PeakVue Parameter and Alarm sets are given later in this chapter.

To illustrate these analysis steps, a peak value (PeakVue) time block of data acquired from a roughing machine gearbox in the steel industry will be used. The time waveform plot is presented below. This data block contains 1024 data points.

PeakVue Time waveform



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The time between each of the vertical lines in the waveform represents the time for one revolution (467 RPM = 7.78 RPS; 1 rev = 1/7.78 = .1285 sec = 128.5 msec). The Fmax for this acquisition was set at 200 Hz; therefore the duration of each time increment for which peak values were captured is the inverse of 2.56 times 200 or 1.953 msec (1/2.56 * 200 = 1/512 = .001953 sec). Note that the time block of 2.0 sec corresponded to 15.56 revs (2 sec * 7.78 RPS = 15.56 revs).

Note the Pk-Pk impacting value observed over this time period was approximately 11 g's (8.70 + 2.03 g's). In addition to the level of impacting, there seems to be a repeatable pattern of increased impacting at intervals of approximately every 2+ revs. The time spacing between impacts is short relative to time per rev. This pattern in the impact time waveform is typical for a defective roller (or multiple) passing in and out of the load zone at the rate of the cage frequency (FTF).

To obtain further verification of a roller defect, examine the PeakVue spectral data presented below that was computed from the impact time data block. The roller defect at 40.6 Hz with harmonics are present (BSF = 5.216 x RPM). The defect frequencies are sidebanded with cage (were clearly amplitude modulated in the impact time data block of Fig. 8). Additionally, the cage frequency at 3.429 Hz (0.441 x RPM) and harmonics are easily identifiable.

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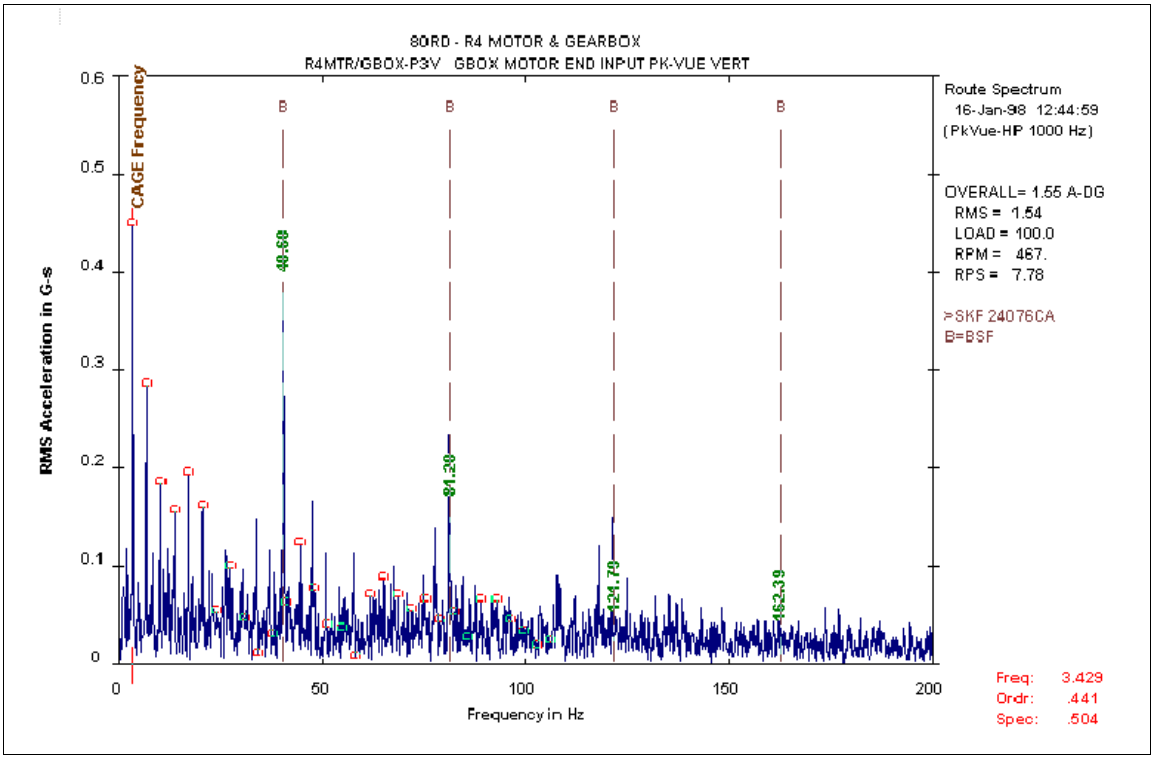
PeakVue Spectrum



It is not uncommon for a roller defect to manifest itself more strongly at two times roller defect. The rough area on the roller may impact once on the outer race and once on the inner race. The spectral data in Figure 9 does not suggest two impacts equally spaced per rev of the roller since the magnitude of spectra at two times fundamental roller spin (.13 g at 2 x BSF at 81.20 Hz) is significantly less than that at one times roller per rev (.28 g at 1 x BSF at 41.6 Hz).

To examine this and other aspects of periodicity, the auto-correlation coefficient was computed from the impact time waveform data. This function is presented below. The independent variable here is time with a maximum value one-half of the original time (2 sec) in the impact time waveform block (1 sec in this case).

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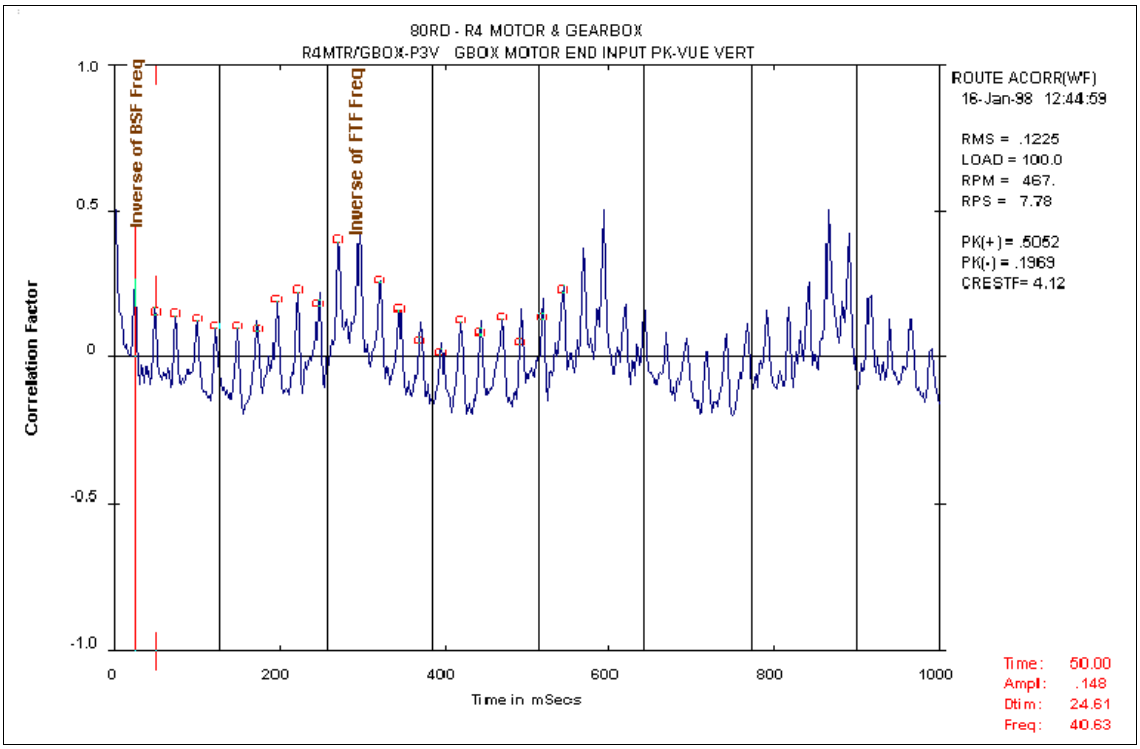
Auto-correlation function plot from PeakVue waveform



The maximum value for an auto-correlation coefficient function ranges between +1 and –1. Perfectly correlated events will be + or –1 and totally uncorrelated events will be zero. The first event with significant correlation in Figure 10 appears at a time equal to the inverse frequency of the BSF (40.63 Hz = .0246 sec/roller rev). The highest amplitude event is at a time equal to the inverse of the cage frequency (1/3.429 = .292 sec = 1/FTF).

The important information presented in the correlation plot is confirmation that the only significant activity with repetitive occurrences are the impacts occurring once per rev of the roller which have variation in amplitude occurring at the repetition rate of the cage.

> ***Note***
>
> *Additional information about the auto-correlation function can be found in the appendices of this manual.*

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Database Setup for PeakVue Points

PeakVue points should be part of all new MasterTrend and RBMware routes and added to existing routes. CSI recommends one PeakVue measurement point per bearing. Measure in the load zone (if possible).

The steps required to add PeakVue points to an existing database are:

1. ··Create a PeakVue Analysis Parameter Set

2. ··Create a PeakVue Alert Set

3. ··Add PeakVue points to each bearing

4. ··Reorder points in Database Setup

5. ··Reorder points in Route Management

Recommended PeakVue Parameters

The primary PeakVue parameter which should be used for trending PeakVue measurements is "Pk-Pk Waveform". Extensive field experience within PdM programs has shown the trending of PeakVue "Pk-Pk Waveform" has proven to be a reliable indicator for detection of faults caused by impact or impulse events (bearing, gear, lubrication, cavitation and related faults).

The "Pk-Pk Waveform" parameter is not dependent on the analysis bandwidth or frequency of the events. This lack of dependence on analysis bandwidth or frequency permits generic alarm levels to be established.

The most important PeakVue parameters used on typical machinery (not gearboxes) are listed below.

- **Waveform Peak-to-Peak** level from the PeakVue time waveform (this value has proven to be the most reliable PeakVue trending value or indicator of impending problem conditions or faults)
- **Total Spectral Energy** is the Digital Overall of the entire PeakVue spectrum after the waveform signal has passed through the high-pass filter and is submitted to the FFT algorithm (not the analog overall of PeakVue)

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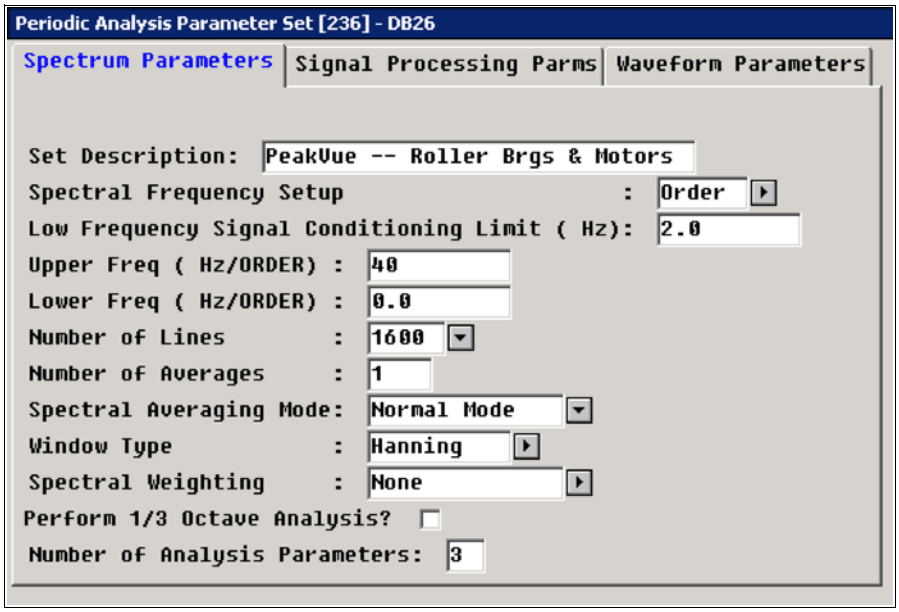
- **Waveform Crest Factor** measures the ratio between Waveform Peak and Waveform RMS. This parameter indicates how "peaked" the waveform is.

Additional PeakVue parameters can be added as needed. Examples of other parameters include:

- Energy in 4-10 synchronous shaft revolutions (**NxRPM Amplitude**)
- Energy in bands surrounding bearing fault frequencies of BSF, BPFO, and BPFI (**Hz Interval, ORD Interval**). If fault frequencies not known, then use two generic bands based on probable number of rollers in bearing. Specifically, for BPFO use a band of [0.25 X N to 0.52 X N] orders; for BPFI, use a band of [0.48 X N to 0.75 X N] orders (where N equals the number of rolling elements);
- Energy from spectral data for sub-synchronous orders (**Hz Interval, ORD Interval**) e.g., 0.2 to 0.8 orders.

The following slides show an example of a PeakVue Analysis Parameter set used on equipment with rolling element bearings (not gearboxes).

Spectrum Parameters Tab


Periodic Analysis Parameter Set [236] - DB26
Spectrum Parameters
Signal Processing Parms
Waveform Parameters
Set Description: PeakVue -- Roller Brgs & Motors
Spectral Frequency Setup : Order
Low Frequency Signal Conditioning Limit (Hz): 2.0
Upper Freq (Hz/ORDER) : 40
Lower Freq (Hz/ORDER) : 0.0
Number of Lines : 1600
Number of Averages : 1
Spectral Averaging Mode: Normal Mode
Window Type : Hanning
Spectral Weighting : None
Perform 1/3 Octave Analysis?
Number of Analysis Parameters: 3

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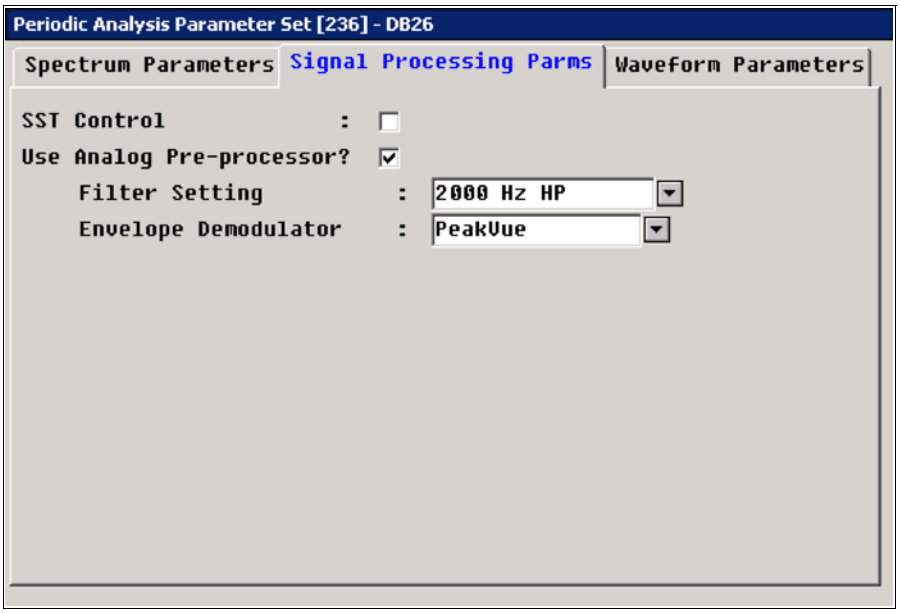
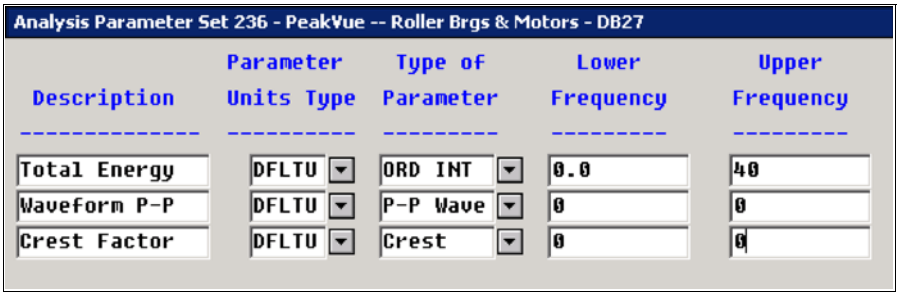
Signal Processing Tab



Analysis Parameters


Analysis Parameter Set 236 - PeakVue -- Roller Brgs & Motors - DB27
Description
Parameter Units Type
Type of Parameter
Lower Frequency
Upper Frequency
Total Energy DFLTU ORD INT 0.0 40
Waveform P-P DFLTU P-P Wave 0 0
Crest Factor DFLTU Crest 0 0

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When monitoring gearboxes, it is very important to include two times gear mesh in the analysis bandwidth. This is to capture possible backlashing in addition to scuffing/scoring on the addendum and dedendum. The high-pass filter should be set higher than anticipated vibration frequencies. For certain gearing faults this could be at three times gear mesh. The problem here is it will often force a high-pass filter set at 5,000 Hz (next choice past 2,000 Hz). If gear tooth impacting is occurring in a gearbox, dominant energy will be in the 1 to 5 kHz range. Additionally, the higher frequencies introduced will experience significant attenuation because of losses from gear teeth to the outer surface where the sensor is mounted. Therefore it is recommended that the high-pass filter be set slightly greater than 2 times the highest gear mesh in the gearbox. If this forces the high-pass filter to exceed 5 kHz, then the high-pass filter should be replaced with a band pass filter which excludes 1 and 2 times any gear mesh within the gearbox.

It is recommended that a measurement point be positioned at each bearing on the gearbox. The high-pass filter setting should be same for each measurement point. The resolution and analysis bandwidth will change. The key is to include up to at least two times gear mesh for any gears on the shaft being monitored and to provide sufficient frequency resolution to resolve that gear mesh being modulated (sidebanded) with either shaft on the gearbox.

The most important PeakVue parameters to use on gearboxes are listed below:

- **Waveform Peak-to-Peak** level from the PeakVue time waveform (this value has proven to be the most reliable PeakVue trending value or indicator of impending problem conditions or faults)
- **Total Spectral Energy** is the Digital Overall of the entire PeakVue spectrum after the waveform signal has passed through the high-pass filter and is submitted to the FFT algorithm (not the analog overall of PeakVue)
- **Waveform Crest Factor** measures the ratio between Waveform Peak and Waveform RMS. It indicates how "peaked" the waveform is.
- Energy surrounding one times gear mesh and two times gear mesh (**Hz Interval, ORD Interval or NxRPM Amplitude**). The width of the band should include a minimum of ±3 times the highest speed shaft involved in the gear

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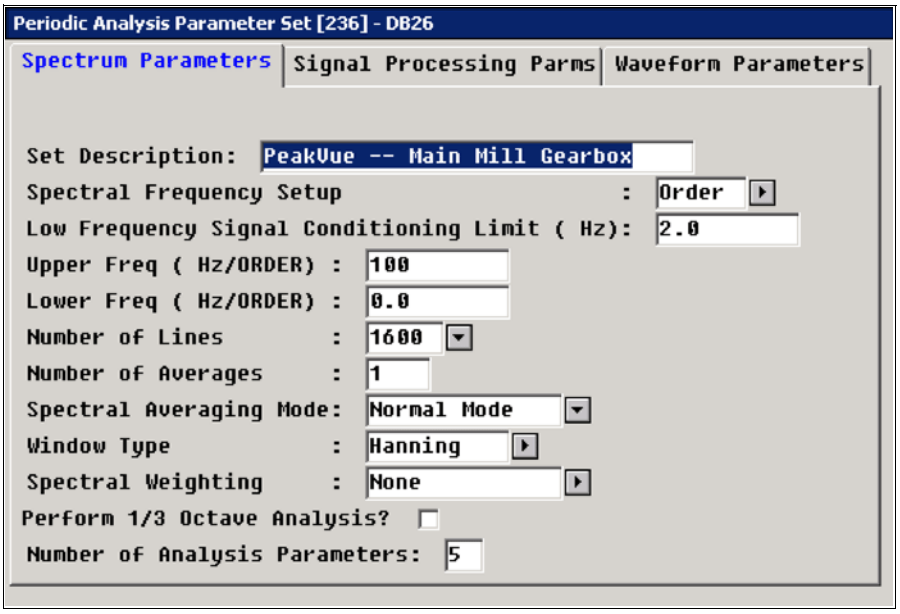
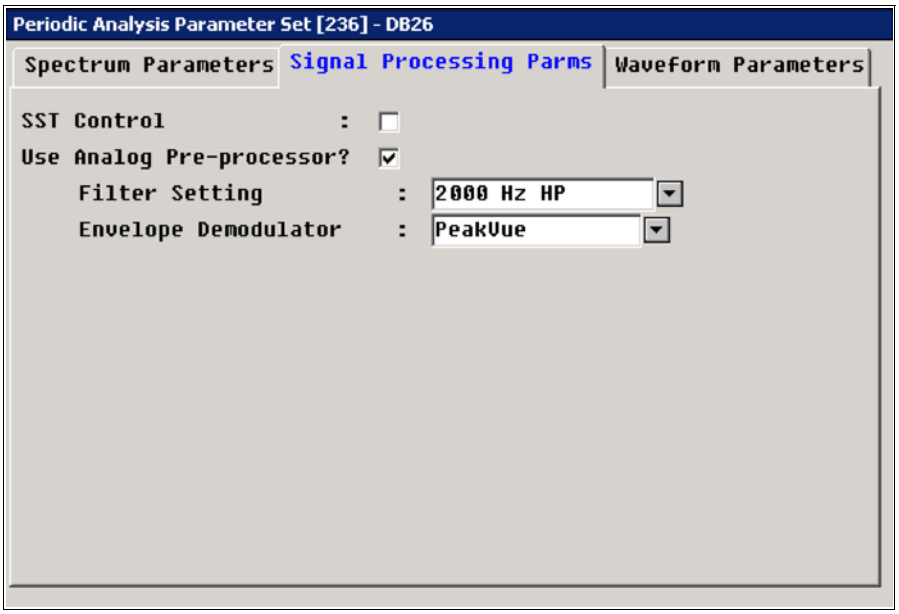
- Energy of synchronous harmonics of shaft speed (for each shaft speed -- **NxRPM Amplitude**)

The following slides show an example Analysis Parameter Setup for a gearbox. The gearbox is a single reduction with 30 teeth on the input gear. Input speed ranges from 600 - 750 rpm.

Spectrum Parameters Tab


Periodic Analysis Parameter Set [236] - DB26
Spectrum Parameters
Signal Processing Parms
Waveform Parameters
Set Description: PeakVue -- Main Mill Gearbox
Spectral Frequency Setup : Order
Low Frequency Signal Conditioning Limit (Hz): 2.0
Upper Freq (Hz/ORDER) : 100
Lower Freq (Hz/ORDER) : 0.0
Number of Lines : 1600
Number of Averages : 1
Spectral Averaging Mode: Normal Mode
Window Type : Hanning
Spectral Weighting : None
Perform 1/3 Octave Analysis?
Number of Analysis Parameters: 5

Signal Processing Tab



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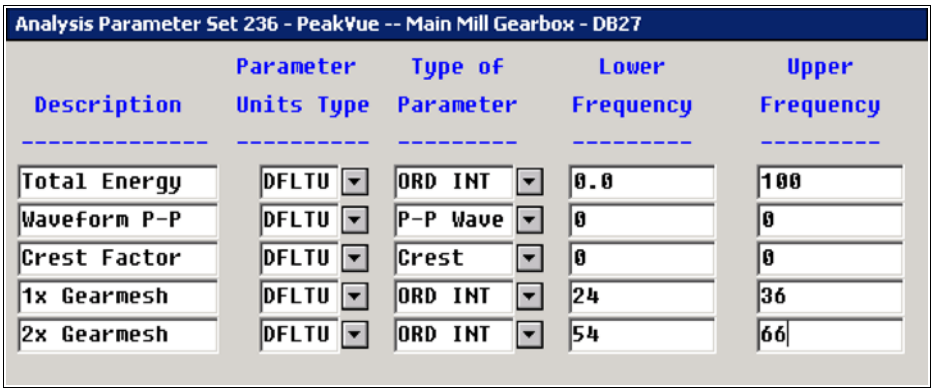
Analysis Parameters



A note about AP Sets

When using an order-based parameter set, the analyzer multiplies the order value (specified for Upper/Lower Frequency For FFT Analysis) times the RPM that is entered during data collection. If this results in an upper frequency value that falls between available frequency selections, the analyzer will default to the next higher selection for this value.

One hundred orders of rotation, in the example above results in a spectrum that extends beyond 3x gearmesh (100 orders = 30 teeth x 3.333). It is important to also consider the frequency spans are available on the 2120 and what the resulting measurement bandwidth will be. Bandwidth (BW) is:

BW = Frequency Span (Hz) / Lines of Resolution (LOR)

To make matters worse, this machine is variable speed. The Fmax, based on 100 orders of rotation may change depending on the speed.

To evaluate the expected Fmax values for each speed:

- Calculate the minimum Fmax, multiply 600 rpm by 100 and divide by 60 to get Hertz. [(600 x 100) / 60] = 1,000 Hz.
- Calculate the maximum Fmax, multiply 750 rpm by 100 and divide by 60 to get Hertz. [(750 x 100) / 60] = 1250 Hz.

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- Evaluate the answers against the Fmax filters available on the 2120. The 2120A has many available frequency spans from DC to 80 KHz. What Fmax filters are closest to the Fmax values calculated above? One way to determine the available spans is to go into the ANALYZE mode on the 2120 and select monitor spectrum. Enter the frequency span calculated for minimum speed then press enter. Observe what the Fmax is on the spectrum. That is the nearest available span. Repeat the test using the Fmax calculated for the maximum speed.

Another option is to refer to the following list of Fmax filters for the 2120 analyzer.

10 Hz	100 Hz	1 kHz
15 Hz	120 Hz	1.5 kHz
20 Hz	150 Hz	2 kHz
25 Hz	160 Hz	2.5 kHZ
30 Hz	200 Hz	3 kHz
40 Hz	250 Hz	4 kHz
50 Hz	300 Hz	5 kHz
60 Hz	400 Hz	6 kHz
75 Hz	500 Hz	8 kHz
80 Hz	600 Hz	10 kHz
	750 Hz	20 kHz
	800 Hz	40 kHz
		80 kHz

1000 Hertz is an available Fmax for 600 rpm turning speed

1500 Hertz is an available Fmax for 750 rpm turning speed

Calculate the resulting Bandwidth for each Fmax. Assume 800 LOR

A Fmax of 1000 results in a BW = 1000 Hz / 800 LOR = 1.25 Hz/line

A Fmax of 1500 results in a BW = 1500 Hz / 800 LOR = 1.875 Hz/line

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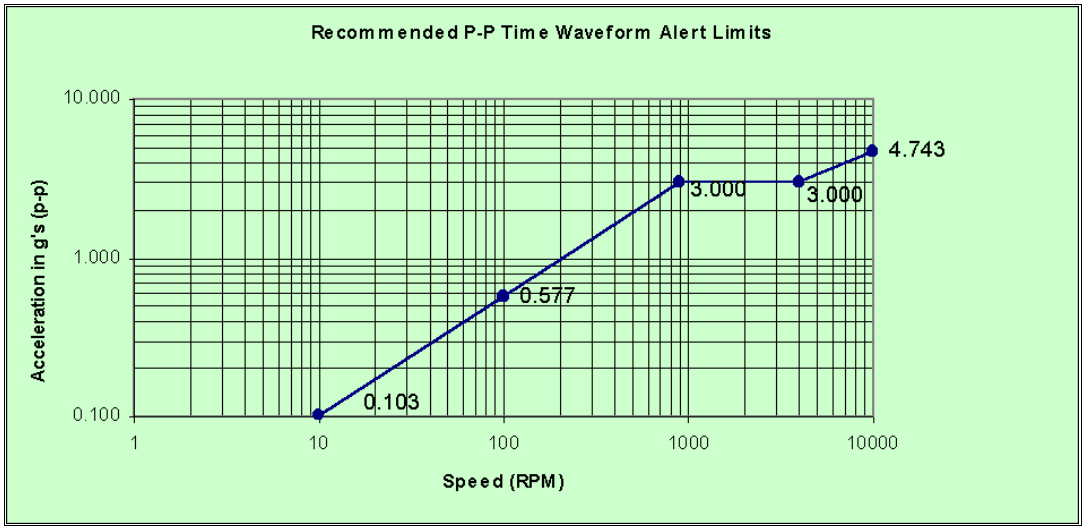
Is the resulting bandwidth acceptable throughout the speed range? If not, we might increase the lines of resolution or change the number of orders measured in the AP Set.

PeakVue Alarm Limits

Alert/Fault levels for normal vibration analysis are generally set based on the spectral data. For stress wave analysis, the variation in spectral data can be significant and unreliable.

The parameter to use for alarming in PeakVue data is the "Pk-Pk" value of the impacting (PeakVue) time waveform. The qualifying parameter is the speed of the machine. For bearing faults, sufficient experience permits the setting of generic "Alert/ Fault" alarm levels. The faults (impacting) occurring on the inner race will see more attenuation than those on the outer race. Hence it is recommended that Alert/Fault levels be set up for the inner race. If the fault is identified to be the outer race, then Alert/Fault levels are increased by a factor of 2.0. For roller defect, increase inner race levels by 1.5.

For PeakVue Time Waveform Peak to Peak Alert levels, the following chart shows how magnitudes typically vary with speed. Note that PeakVue amplitudes are very sensitive to speed in the ranges from 10 to 900 RPM and from 3000 to 10,000 RPM, but are constant between 900 and 3000 RPM.



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The following table takes these speed sensitivities into account by providing formulas that can be used to calculate PeakVue Time Waveform Peak to Peak "Alert" and "Fault" Alarm levels for a wide range of speeds ranging from 10 RPM up to over 10,000 RPM.

PeakVue Time Waveform Alert Alarms for Bearing and Gear Problems at Various Speeds[1,2]

Component RPM	R. E. Bearing Faults		Gear Faults	
	Inner Race, Cage or Rolling Element Fault	Outer Race Fault	Worn or Scored Teeth[3]	Cracked Teeth[4] (Fully Loaded)
0 - 900	$\text{Nominal Speed Alarm} \times \left[\frac{\text{Actual RPM}}{900}\right]^{0.75}$			
901 - 4000 (Nominal Speed)	3 g	6 g	3 g	6 g
4001 - 10,000	$\text{Nominal Speed Alarm} \times \left[\frac{\text{Alarm RPM}}{4000}\right]^{0.5}$			
10,001 - Up	5 g	10 g	5 g	10 g

Notes:

1.····· Tabel V is intended to act as a Guideline providing suggested “Alert” and “Fault” Alarms to be applied to PEakVue waveforms for various faults as listed. These alarm amplitudes will likely be refined with further experience, statistical analyses, and investigations.

2.····· Alarms are applied to the Peak-Peak levels found in PeakVue Time Waveforms. If this waveform alarm is violated, then the analyst will refer to the PeakVue Spectrum to determine the cause of the problem (rolling element bearing, gear lubrication, etc.)

3.····· Applies either to gears having numerous worn teeth around periphery or to gears having deficient lubrication causing scoring/scuffing of gear tooth surfaces.

4.····· Alarms given for “Cracked Teeth” assume gears are fully loaded. If gears are operated at or near no-load conditions, alarm levels should be reduced by a factor of 2. It is a good practice to fully load gearing when it is being evaluated by eithervibration or stress wave analysis if possible.

5.····· Limited experience to date on precision machinery (i.e. machine tools) suggests “Alert/Fault” alarm levels should be reduced by a factor of 2.

6.·····Set Alarm Level for PeakVue Fault = 2x PEakVue ALERT Alarm.

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Examples Applying PeakVue Alarms to a Variety of Faults at Various Speeds (from the above Table)

1.·· Suspected Outer Race Bearing Fault on 1793 RPM Motor:

From Table at 1793 RPM

PeakVue Alert Alarm = 6.0g in Time Waveform (Look for multiple BPFO Frequencies in PEakVue Spectrum)

2.·· Suspected Inner Race Bearing Fault on 1793 RPM Motor:

From Table at 1793 RPM

PeakVue Alert Alarm = 3.0 g in Time Waveform (Look for multiple BPFI Frequencies in PeakVue Spectrum)

3.·· Suspected Worn Teeth on an 8000 RPM High-Speed Pinion:

From Table at 8000 RPM

$$PeakVue\ Alert\ Alarm = \left(\frac{8000}{4000}\right)^{0.5} \times 3g = 1.414 \times 3 = 4.2g\ (in\ TWF)$$

(Look for high amplitude at 1xGMF [and occasionally at 2xGMF and/or 3xGMF] in PeakVue Spectrum if the pinion has worn or scored teeth.)

4.·· Suspected Broken Tooth on an 8000 RPM High Speed Pinion:

From Table at 8000 RPM

$$Peak\ Vue\ Alert\ Alarm = \left(\frac{8000}{4000}\right)^{0.5} \times 6g = 1.414 \times 6 = 8.4g\ (in\ TWF)$$

(Look for multiple pinion running speed harmonics in PeakVue Spectrum and for 1 or 2 pronounced pulses/revolution of Pinion in PeakVue TWF.)

5.·· Suspected Outer Race Fault on a 250 RPM Machine:

From Table at 250 RPM

$$PeakVue\ Alert\ Alarm = \left(\frac{250}{900}\right)^{0.75} \times 6.0g = 0.383 \times 6.0g = 2.3g\ (in\ TWF)$$

(Look for multiple BPFO frequencies in PeakVue spectrum.)

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6. ··Suspected Inner Race Fault on a 250 RPM Machine:

From Table at 250 RPM

$$PeakVue\ Alert\ Alarm = \left(\frac{250}{900}\right)^{0.75} \times 3g = 0.383 \times 3g = 1.15g\ \textit{(in TWF)}$$

(Look for multiple BPFI frequencies in PeakVue Spectrum.)

Other analysis parameters which are calculated from the spectrum, such as the overall digital energy (entire analysis bandwidth), synchronous and nonsynchronous parameters, are meaningful trending parameters. The Alarm values set for these parameters will have to be learned and/or based on reference spectral values (recommend multiply by 4-5X) and experience.

As mentioned earlier, watch the normal vibration spectrum for signs of bearing faults at the calculated defect frequencies. When faults are visible at FTF, BSF, BPFO and BPFI, the faults have progressed to the final stages of the bearing's remaining life.

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Lubrication Issues and PeakVue

Lubrication-induced faults are generated from two sources: Impacting and Friction. Lubrication problems can generate considerable PeakVue amplitudes, sometimes 25 to 50 g's, or greater. Friction-induced lubrication problems excite much higher frequencies than do impact-induced faults, and also generate very different looking PeakVue spectra. An impact will typically show bearing fault frequencies, particularly BSF harmonics, whereas friction-induced problems generally do not result in PeakVue spectra with well defined, discrete frequencies. Instead, friction always causes an elevated noise floor within the spectrum with random, broadband frequency content.

The higher frequency components generated from lubrication faults experience significant attenuation during propagation to the outer surface of the gearbox. For this reason, the sensor mounting should be a flat magnet or stud mount.

Friction Induced Lubrication Problems

Friction induced lubrication problems cause excessive g levels >50g. Since friction-induced faults generate high frequencies in the range of 10,000-15,000 Hz, much of the signal rapidly dissipates before reaching the sensor. The TWF is usually random with little or no periodic events.

Friction-induced lubrication problems excite a wide range of high frequencies, typically ranging from just below 5000 Hz up to frequencies exceeding 15,000-20,000 Hz. The spectrum will have an elevated noise floor consisting of random, broadband frequency content.

Impact Induced Lubrication Problems

Impacting is typically caused by metal-to-metal contact due to insufficient lubrication (and/or incorrect lubricant viscosity). If metal-to-metal contact occurs in a bearing, the PeakVue spectrum will typically show periodic content. TWF amplitudes can range to >25g, but more typically stay within 4-8g range.

Metal-to-metal contact will most often generate bearing defect frequencies – usually BPFO and/or BPFI; however, also commonly excites ball spin (BSF) frequency accompanied by cage frequency (FTF) sidebands.

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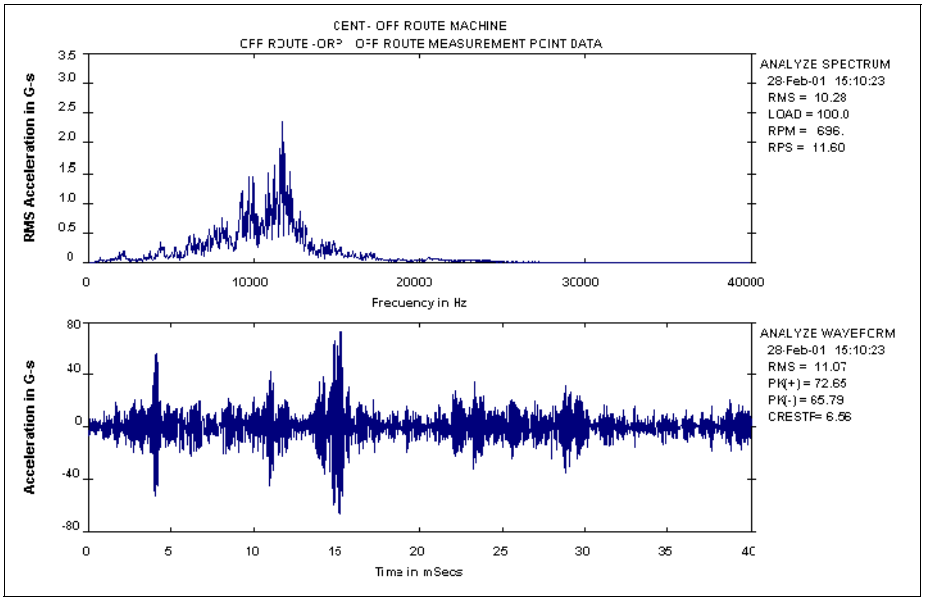
Example 1 - Lack of Lubrication resulting in Friction

The case presented below is an example of lack of lubrication with high friction. The plot below shows a normal spectrum of a drive shaft pedestal bearing. The data were captured using a high frequency 10 mv/g sensor attached with a flat rare earth magnet, on a flat smooth surface, at the top of the pedestal. The data was acquired out to 40 a kHz bandwidth. The time block of data is 40 msec which is less than 1/2 of a revolution (speed = 696 RPM =11.60 RPS; T = 1/ 11.6 = 86.2 msec/rev).

Most energy is in the 6 kHz to 15 kHz range. This is typical for friction-generated events. Once again, this is NORMAL vibration data.

Normal Spectrum and Waveform



To more carefully analyze this bearing, a data block is needed which includes several revs of the shaft sampled at a high rate. A PeakVue measurement was acquired with a 400 Hertz Fmax using a 1000 Hz. High pass filter. The PeakVue spectral data and (partial) time block of data are presented below. The spectral data shows indications of repetitive events occurring at 2x shaft speed with less response at 1X and 2X of BPFI. The most concern should be given to the excessive PK-PK value of 273 g's observed in the PeakVue time waveform. This type of PeakVue waveform and spectrum has classically been the result of metal-to-metal contact indicating lack of lubrication resulting in high friction.

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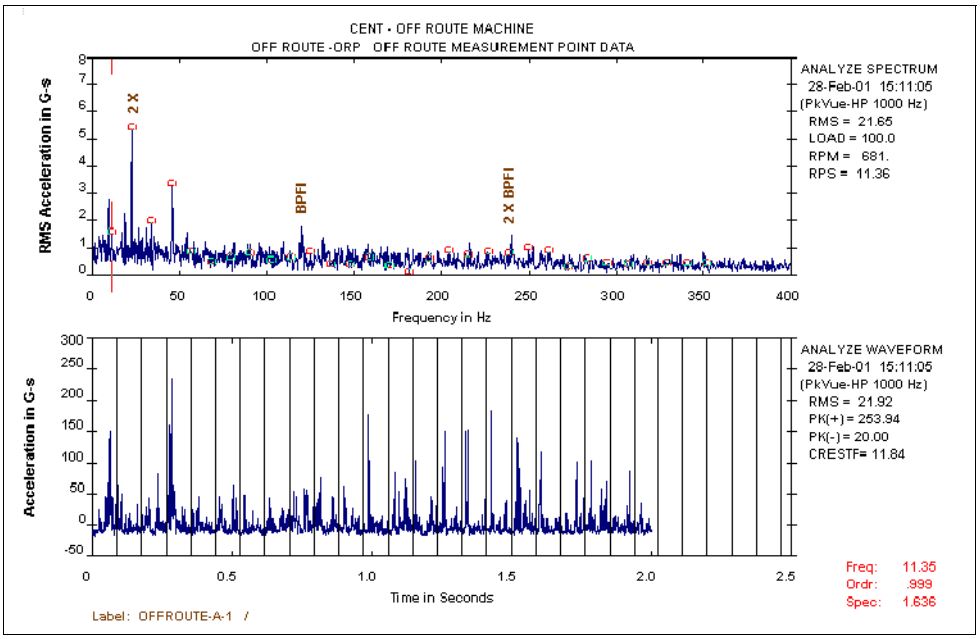
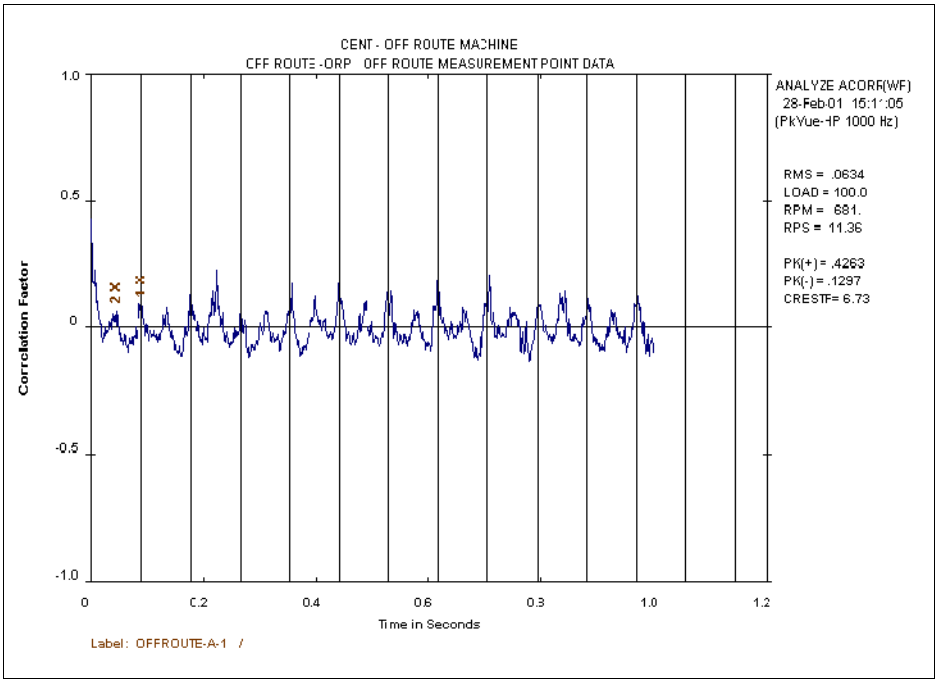
PeakVue Spectrum and Waveform



The auto-correlation coefficient computed from the PeakVue time waveform is presented below. The periodic behavior at two times running speed is clearly indicated here, but the presence of BPFI is not indicated.

Auto-correlation Function



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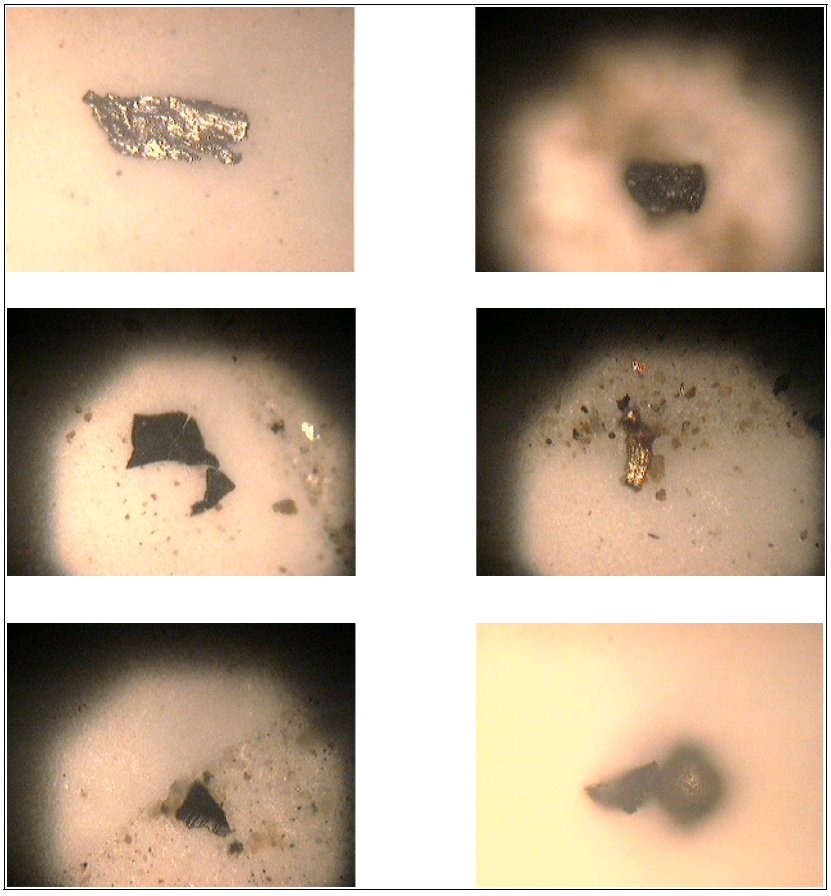
To verify metal-to-metal contact was occurring, an oil wear debris analysis was carried out on an oil sample from the bearing. The pictorial results are presented in Figure 22. This data verified metal-to-metal contacting was occurring.

Oil Sample Results

Database:	Example.rbm	Meas. Point:	WDA - Wear Debris Analysis
Area:	WDA - Wear Debris Analysis	Sample No:	Bearing
Equipment:	WDA - Wear Debris Analysis	Sample Date:	3/5/01 3:56 pm



Wear debris analysis revealed a moderate distribution of metallic platelets, chunks, spheres, and black oxides. All particles are typical of insufficient lubrication and metal to metal contact.

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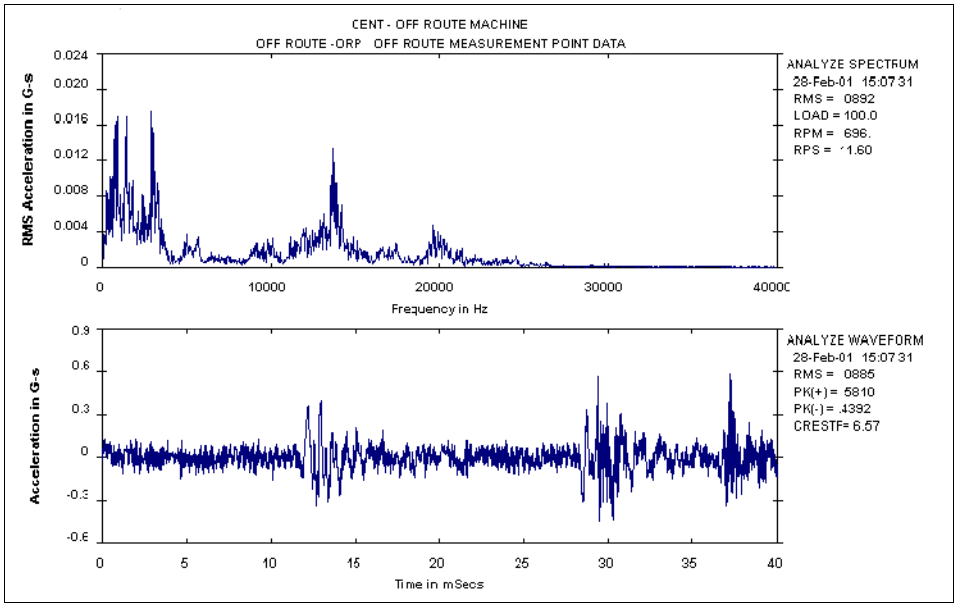
Example 2 - No Lack of Lubrication

The case presented below was measured on another drive shaft pedestal bearing ñ similar to the one in the case above. This bearing does not have a lack of lubrication. The plot below shows the normal spectrum and waveform.

Unlike the first bearing, this one was not experiencing any large, randomly occurring events. The spectrum shows significant energy in the 1 to 4 kHz range as well as in the 12 to 15 kHz range. The lower frequency range is consistent with what is expected for impacting and the upper range is consistent for what is expected for friction.

Normal Spectrum and Waveform



To more carefully analyze this bearing, a data block is needed which includes several revs of the shaft sampled at a high rate. A PeakVue measurement was acquired with a 400 Hertz Fmax using a 1000 Hz. High pass filter. The PeakVue spectral data and (partial) time block of data are presented below. The maximum PK-PK values were 2.4 g's (significantly lower than the 273 g's on the bearing in example 1). In the spectra data, events are clearly present at 2X shaft speed and at BPFI (which is sidebanded with 2x shaft speed).

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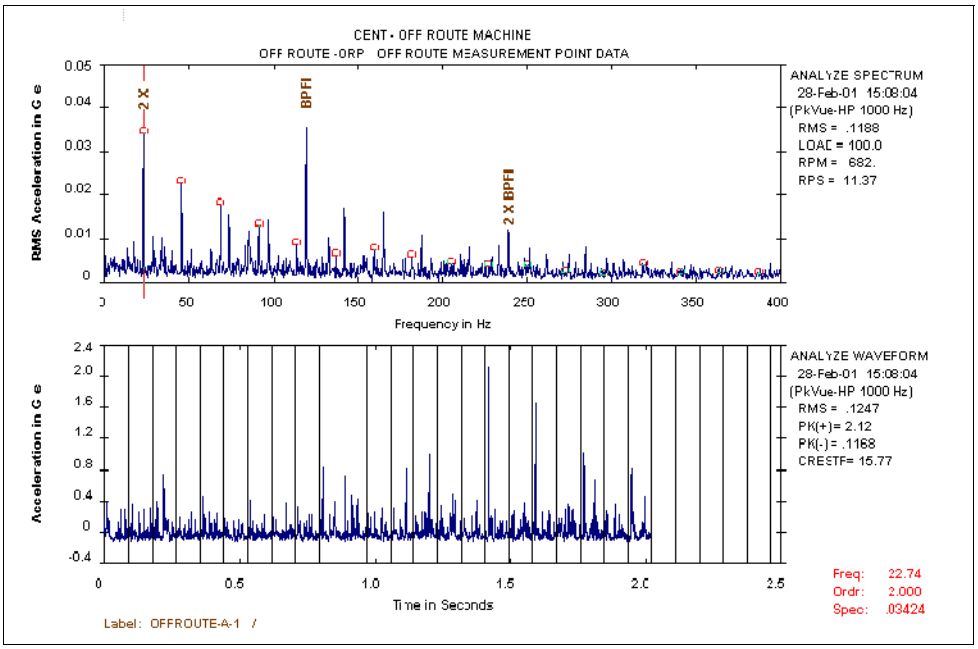
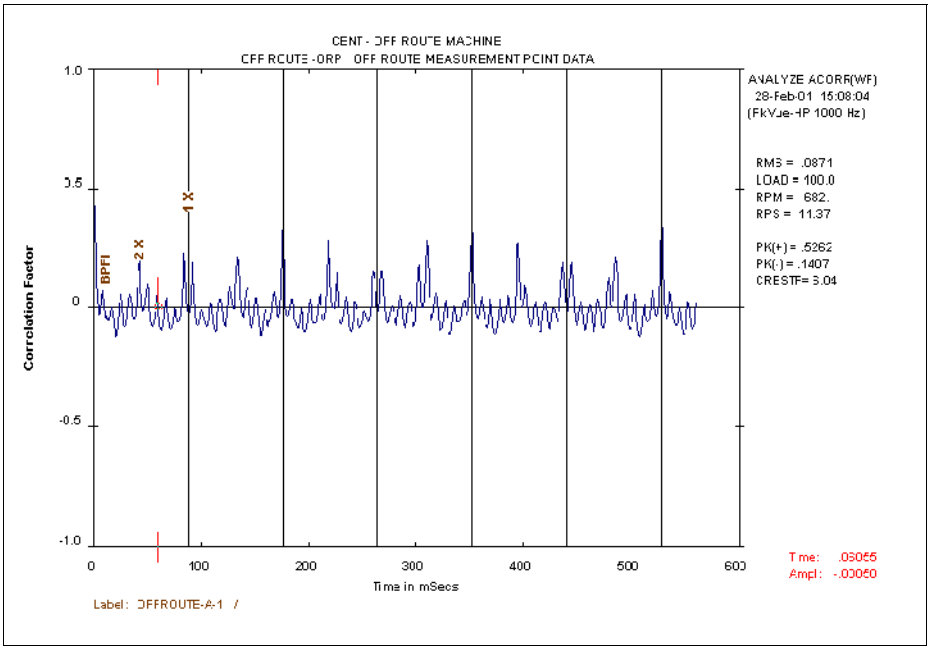
PeakVue Spectrum and Waveform



The auto-correlation coefficient computed from the PeakVue time waveform is presented below and clearly shows the BPFI and 2X activity is the only correlated activity present. The second bearing was not subjected to the significant lubrication deficiency and friction, however, it has a few defects. Based on the levels, the defects are at an early stage of failure.

Auto-correlation Function



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Note

Additional information about the Auto-correlation function can be found in the appendices of this manual.

Sensor Sensitivity and Maximum g level:

A 100 mv/g accelerometer can measure 50 g's before overloading. A 10 mv/g accelerometer can measure 500 g's.

ICP type accelerometers have a full scale output of 5 volts. The maximum acceleration that a sensor can measure, before overloading, is calculated using the following formula.

Max g's = 5 volts / Sensor sensitivity

For example: A 10 mv/g accelerometer can measure plus and minus 500 g's.

500 g's = 5 volts / .01 v/g

For example: A 100 mv/g accelerometer can measure plus and minus 50 g's.

50 g's = 5 volts / .1 v/g

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Slow Speed Technology

Section 4

Objectives

- Recognize the benefit of the Slow Speed Technology (SST) feature for low-frequency measurements.
- Practice the setup of SST measurements from Master-Trend as well as the 2120.

CSi means Reliability Training

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Introduction

The SST feature improves the quality of the very low-frequency vibration data generally encountered in slow turning machines. We will consider machines running below 180 RPM as slow speed. A few important measurement considerations **must** be observed.

Use a low-frequency, low-noise, high sensitivity accelerometer to collect data (500 Mv/g or higher). Integrate the data from acceleration to velocity units using **ANALOG** integration.

Apply the SST correction feature to the measurement point or as an additional data point acquired in the Analyze / Acquire Spectrum option on the 2120 analyzer. The SST feature corrects for the deterministic error occurring with the use of the analog integrator. The SST correction is applied after the data averaging is done, so the end result is the ability to see the low-frequency events at higher measured amplitudes, allowing for easier detection.

Accelerometer Selection

To obtain the useful information required to perform analysis on slow speed equipment, a *low-frequency*, *low-noise* accelerometer will provide the results. The sensor should be minimally responsive to temperature measurement and should have a sensitivity of at least 500 mV/g.

Most accelerometers have a dynamic range of 100 to 120 dB, which means that the analyzer will have the limiting dynamic range. If possible when choosing an accelerometer, a ceramic piezoelectric crystal is preferable to a quartz crystal and a shear mode accelerometer is preferred to a compression mode accelerometer.

When comparing displacement, velocity and acceleration, it is evident that displaying the data in units of displacement enhances the low-frequency data and acceleration depresses the low-frequency data. However, a drawback is that a displacement probe must be permanently and securely mounted so the portability factor is lost.

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Placing a displacement probe on each measurement point also increases the equipment cost for your program. Integrating the data to velocity may be the best compromise.

When integrating data for SST, ANALOG integration is required for a number of reasons.

1. ·· Analog integration attenuates the vibration signal above the F_{max} of the spectrum and thus improves the dynamic range of the analyzer in the lower frequency region.

2. ·· Analog integration reduces the low-frequency flare-up known as ski slope, which digital integration can actually increase.

3. ·· Analog integration produces a known effect (deterministic error) on the vibration data that the Model 2120 Machinery Analyzer can correct with the SST (Slow Speed Technology) feature.

The recommended measurement procedure is:

1. ·· Use a low-frequency accelerometer.

2. ·· Use analog integration.

3. ·· Collect the data with the SST correction enabled.

To show the difference in the three different collection methods, we will compare data from one measurement location collected three different ways.

1. ·· Acceleration converted to velocity with DIGITAL integration.

2. ·· Acceleration converted to velocity with ANALOG integration and No SST correction.

3. ·· Acceleration converted to Velocity with ANALOG integration and SST correction applied to the data.

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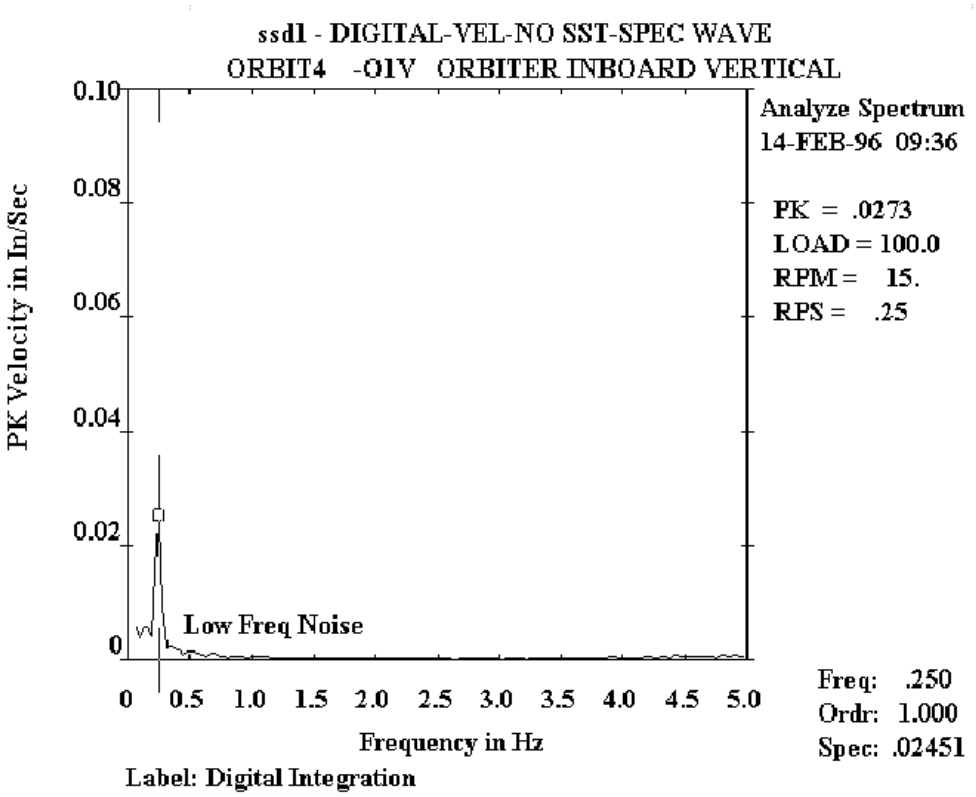
The data was collected using a CSI model A320LF low-frequency accelerometer with a sensitivity of 0.5 volts/g. Data is displayed to a F_{max} of 5 Hz although the data was collected to a F_{max} of 20 Hz with 800 lines of resolution and six non-overlapped averages.



This data does allow us to see the 15 CPM turning speed vibration but notice the low-frequency noise and the small amount of ski-slope occurring below turning speed.

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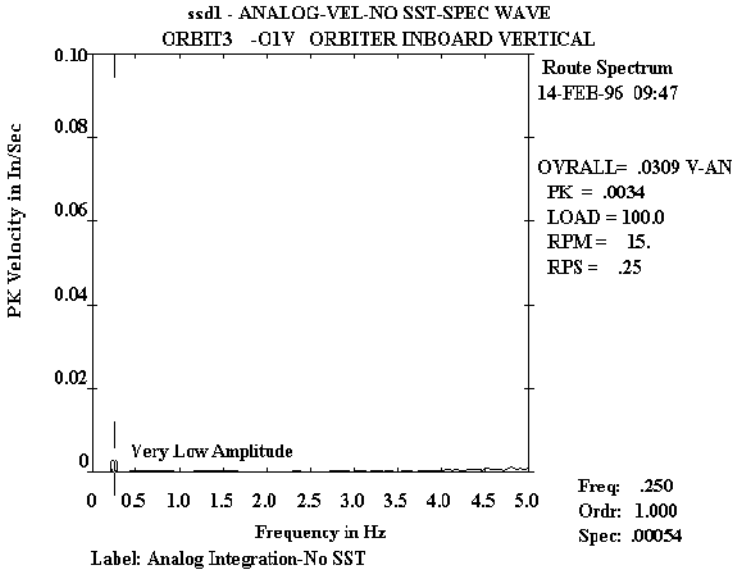
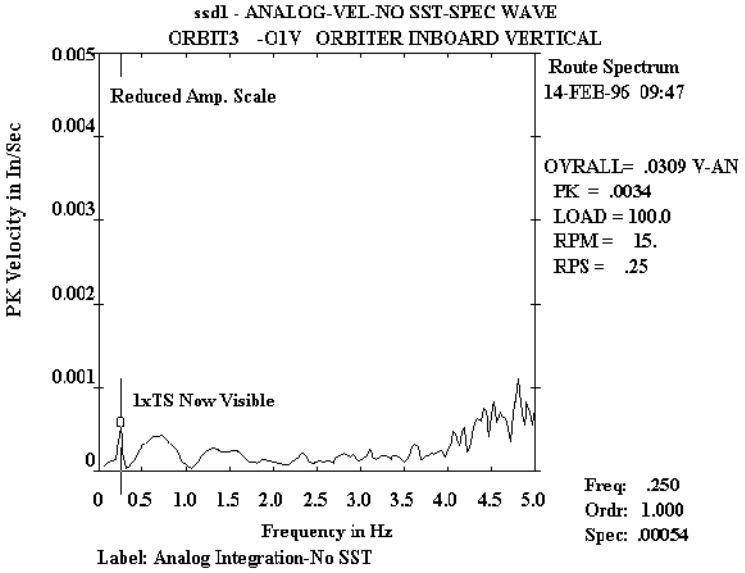
The full-scale plot value is the same as the previous data. It is easy to see that we don't have the same low-frequency noise problem that we had with digital integration. We don't even seem to have data.

If we expand our amplitude scale, we do see that the turning speed vibration is present, although at a very low amplitude.





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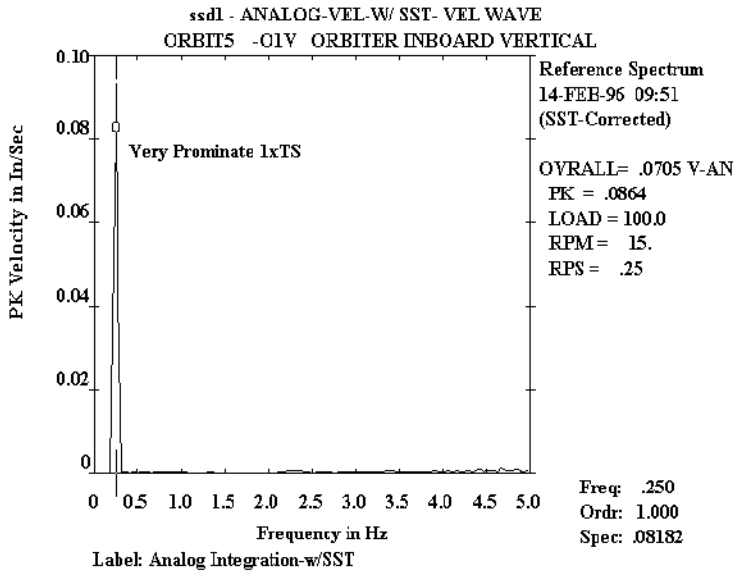
This data clearly shows the benefit of using analog integration with the SST correction feature enabled. This data boldly shows the 1xTS vibration with no background noise visible in the vibration data.



If an accelerometer is chosen, keep in mind that the acceleration amplitudes will be very low. Low amplitudes once again bring us back to the discussion of the floor noise. If the floor noise of the accelerometer and analyzer is high, then that particular setup may not work for collecting low-frequency data. A multi-spectra plot is shown on the next page displaying the long-term average of the random noise floor of four different accelerometers. The data is displayed in displacement.

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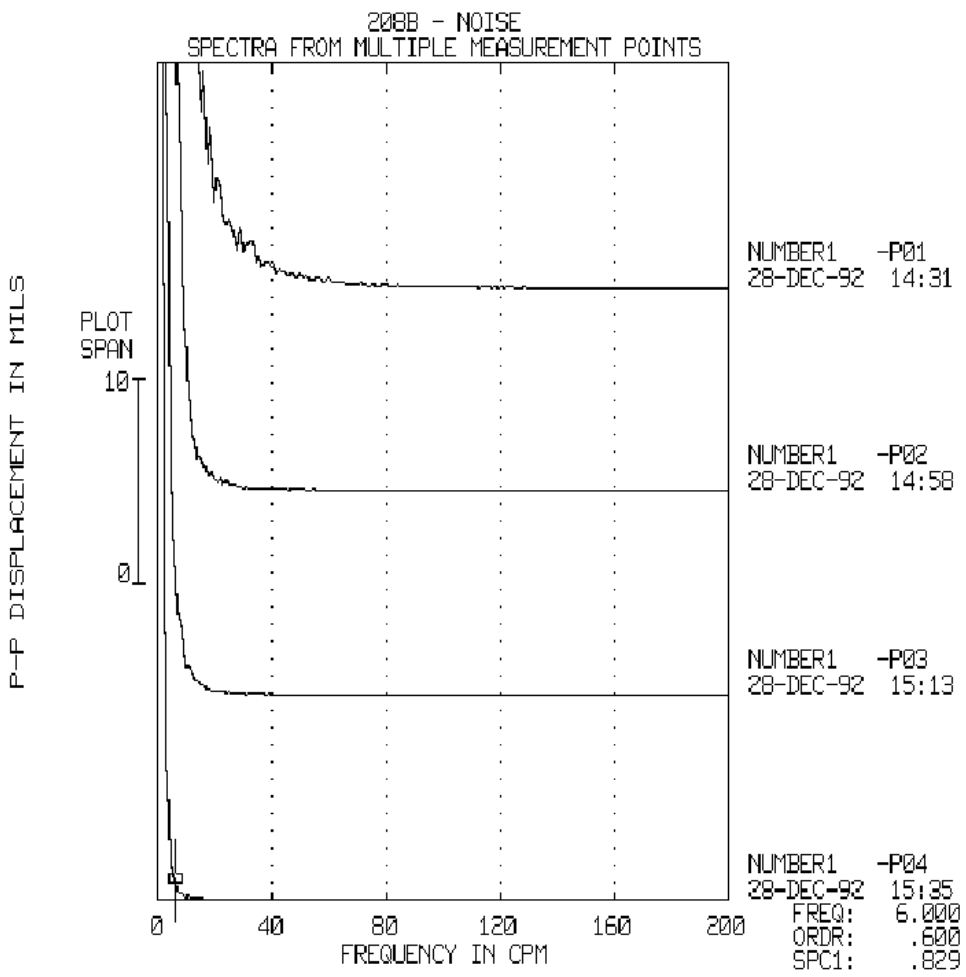

PO1 - Typical high-performance standard unit

PO2 - Low-frequency unit

PO3 - Low-frequency, low-noise unit

PO4 - Ultra-quiet seismic unit

Most of the typical off-the-shelf accelerometers will have a low-frequency roll-off filter to attenuate the low-frequency signals. In this case, the actual amplitude the analyzer is receiving has been attenuated before it processes the signal. If the analyzer also has a low-frequency roll-off filter, then it may again decrease the signal amplitude. It is highly probable that the displayed amplitude is not the actual amplitude of the vibration of the machine. **The specialized low-frequency, low-noise accelerometers are closer to the actual amplitude**.

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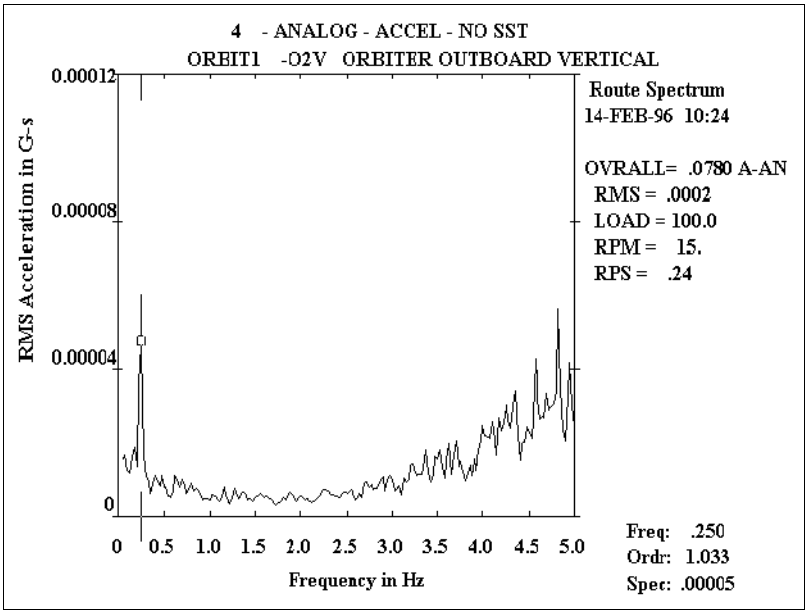
When looking at the specifications on an accelerometer, you will see the frequency response ranges. Generally, there is a specification at which the amplitude will be 3 dB down, or 30 percent error from the actual data. This frequency range may be utilized with the understanding that an error is involved but that the data may be trended since the error will be consistent. It is probably preferable to use an accelerometer with the frequencies of interest included in a range with no errors.

If you doubt the quality of the measurement, then look at the display and observe the ratio between the signal being evaluated and the displayed level of noise on either side of it. If the signal stands out boldly above the noise by a ratio of 10 times or more, then the probability of noise corruption is very low. You can have confidence in the trend data.

If the signal sits on a noise floor that makes up 25 to 50 percent of the displayed amplitude, then the probability of noise corruption is high. You cannot trust the amplitude. In this case, you still have an accurate frequency by which to determine the 1xTS peak.

Let's take a practical look at low-frequency data collected with low-frequency vibration sensors compared to the data collected on the same machine with a standard transducer.

The first data plot comes from a standard 0.1 volt/G accelerometer with a low-frequency cut off of about 1 Hz.



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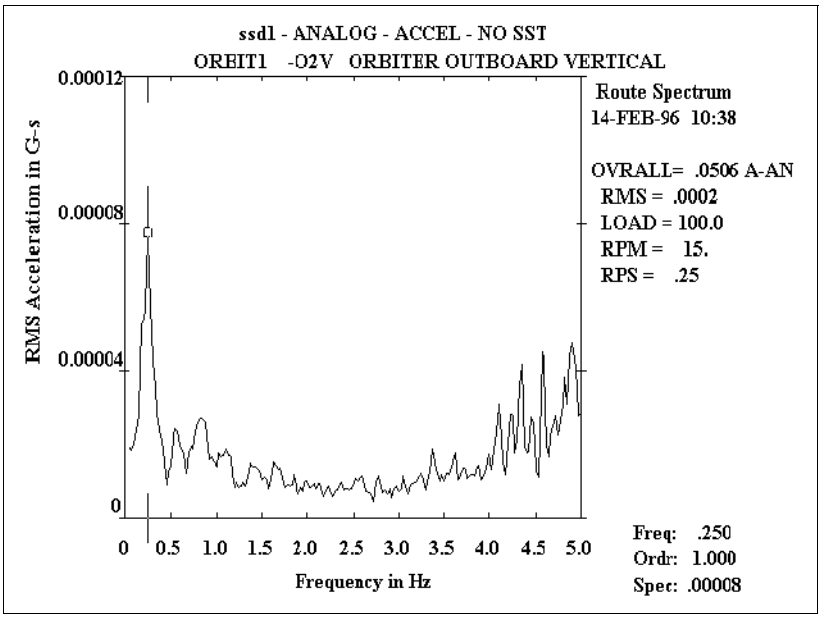
The next data plot comes from a low-frequency low-noise accelerometer with a sensitivity of 0.5 volts/G and a low-frequency cutoff of 0.2 Hz. Notice how much better the amplitude of the 1xTS vibration appears in this data.



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Practical Considerations

- Handheld mounts are unacceptable, because you cannot hold the sensor steady enough.
- From a cost perspective, you recover the money spent for a better accelerometer through the hours of time saved during data collection. Using a marginal accelerometer requires extended averaging to improve the repeatability of the data. This approach always yields measurements that take more time and incur more errors.
- Consider the vibration environment of the machine and its supporting structure. Low-frequency vibrations are not attenuated by structures and cannot be attenuated by any practical scheme of mechanical shock absorbers or dampeners. If a machine has an internal vibration of 5 mils P-P with a structural vibration of 10 mils P-P in the same low-frequency band, you cannot conduct vibration analysis.
- In general, special equipment and procedures required for monitoring extremely low-frequencies do not intermix easily with regular PDM data collection. Successful programs handle low-frequency monitoring in separate routes with analysis parameter sets (APS) tailored for each measurement point. Tailoring APS minimizes the collection time for each point without corrupting the integrity of the data.

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Measurement Variables

Transducer Mounting

Several mounting techniques are available. The most popular is the magnet mount. As mentioned before, when using the magnet mount, it is best to roll the magnet onto the machine structure instead of allowing it to slap onto the machine. This is very important when it comes to the more sensitive specialized accelerometers. You will definitely overload them and possibly cause damage to the accelerometer.

Another popular technique is the handheld method of mounting accelerometers. This technique, as mentioned earlier, is simply not acceptable. The human hand is not able to hold it steady enough for the required amount of time to collect the data.

Permanent mounted accelerometers are ideal, but not very cost effective due to the cost of the specialized accelerometers. Some of these accelerometers also require their own charge amplifier that would make them that much harder to mount. From this information, we can see that the magnetic mount is probably the best suited mounting technique for slow speed machinery, with the appropriate precautions taken.

Now we must consider where we will mount the transducer on the machine. Understanding that the amplitudes of the data will be considerably lower than the amplitudes of the faster machinery, it is critical that the data be collected in the load zone of the bearing. This will minimize the transmission path required of the data. When you consider the physical size of most of these slow speed machines, you can understand the low amplitudes. These machines may have shafts ranging from 4 inches to 20 inches in diameter. The machines are very rugged and massive and large amounts of energy would need to be expended to cause high amplitudes of vibration. Hence, there have been instances with bearings in very severe conditions, but with amplitudes only around 0.002 inches per second.

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Thermal and Electrical Settling Time

The physical environment is also very important. You do not want to mount an accelerometer where there is a swirling stream of hot or cold air. Temperature variations will definitely have an effect on the transducer and ultimately on the data collected. During the research for this manual, a low-frequency measurement was attempted on the frame of a paper machine. The variable air circulation in the vicinity of the sensor caused alternating drafts of steam and cold air. As a result, the sensor would not settle down, and the measurement was not successfully completed.

Along with the temperature of the surrounding environment, the difference in temperature between the sensor itself and the structure to which it is being mounted should also be considered. The output signal of the transducer will drift with a change in temperature. The data collector will not be able to differentiate between actual data and the influence of the drift signal. In situations like this, the best solution may be to mount the accelerometer and power it up about an hour before you attempt to make the measurement.

When mounting transducers to the machine, one must be careful in the manner in which it is done. If using the magnetic mount, the transducer and magnet should be rolled onto the machine and, not allowing the magnetic forces to pull the transducer to the machine. The impacting that results when a transducer is slapped on a machine is very high. This increases the amount of stabilization time needed before collecting data with that transducer.

A period of time should be allowed for mechanical stabilization. In addition to mechanical stabilization, the electronic circuits should also be allowed to stabilize once they are powered up. This is common with any electronic circuits including those of the transducers used for monitoring vibration. Typically, if the transducer is powered up as you leave your office, then by the time you reach your first measurement the electronic circuits should be stable, assuming that your first measurement is not just outside your door. It is vital that you let the transducer stabilize in order to capture reliable and repeatable data.

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Cable Motion

Another factor that plays an important role with handheld accelerometers is the triboelectric effect from moving the cable during the data collection process. This occurs when a shielded cable is moved around, bent, or stepped on during data collection, or if you are using a charge mode accelerometer system. The stress, or friction, from the moving of the internal wires causes noise to be induced into the data signal thereby corrupting the data. You need to be aware of this and, when collecting the data, place the analyzer on the floor or hang it from a location that allows it to be stable during the data collection period.

The cable itself should not apply any dynamic force to the sensor. Again, a coiled cable may easily do this if it swings back and forth, not only causing triboelectric noise, but also creating a low-frequency vibration at the sensor. This may give you false readings.

The cable should remain still during data collection to minimize the triboelectric effect. The best cable choice is a twisted-pair, shielded coaxial cable or a coaxial cable with the shield attached at the signal return at both ends.

We should be aware of several things as we go to the field to collect our data. One thing in particular is the effect that electromagnetic interference (EMI) has on the cabling used for data collection. If a strong magnetic field is present, this could prohibit you from collecting the wanted data. It is highly recommended that the cabling not be run near large motors, power transformers, or other current carrying conductors. If you are aware of any high magnetic fields, then you want to use a completely shielded cable for your setup.

As an analyst, you should become familiar with good data on your machines. This is very important so that you will be able to recognize bad data when it has been collected. Cables have a history of needing repair at times. If data is collected with a bad cable, then the data is virtually useless. Along the same lines and probably worse, is the problem of an intermittent cable C one that has a break but makes intermittent contact. This could make part of your data look valid, but again it is useless data.

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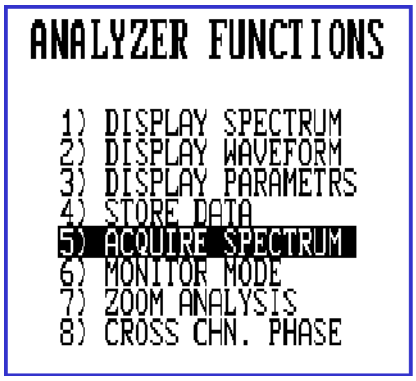
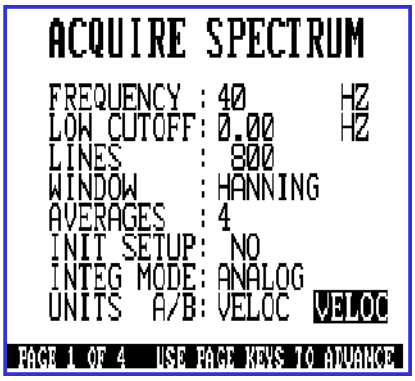
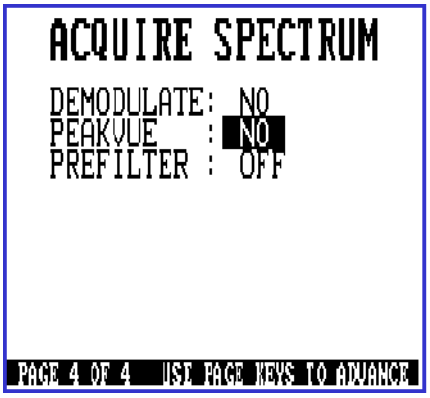
2120 Setup

This feature is accessible from the 2120 Analyze Menu using Monitor Spectrum, Acquire Spectrum or Off Route. Collected data can be saved using Acquire Spectrum if a route point is active on the analyzer. The following screens show the SST set-up in Analyze/Acquire Spectrum. Be sure to use ANALOG integration for SST measurements. Press the **Analyze** key at the top of the 2120 and select Acquire Spectrum. Set-up the first page as shown below using the F_{max} and lines of resolution needed.





Press the **Page** key to examine the setup for the other three pages.



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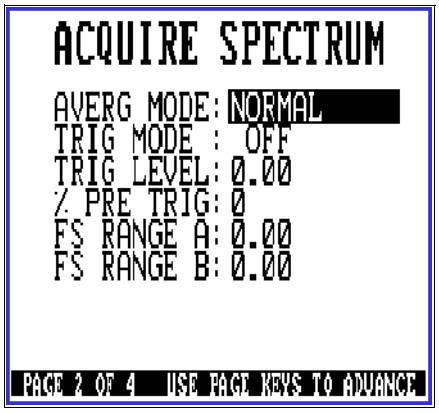
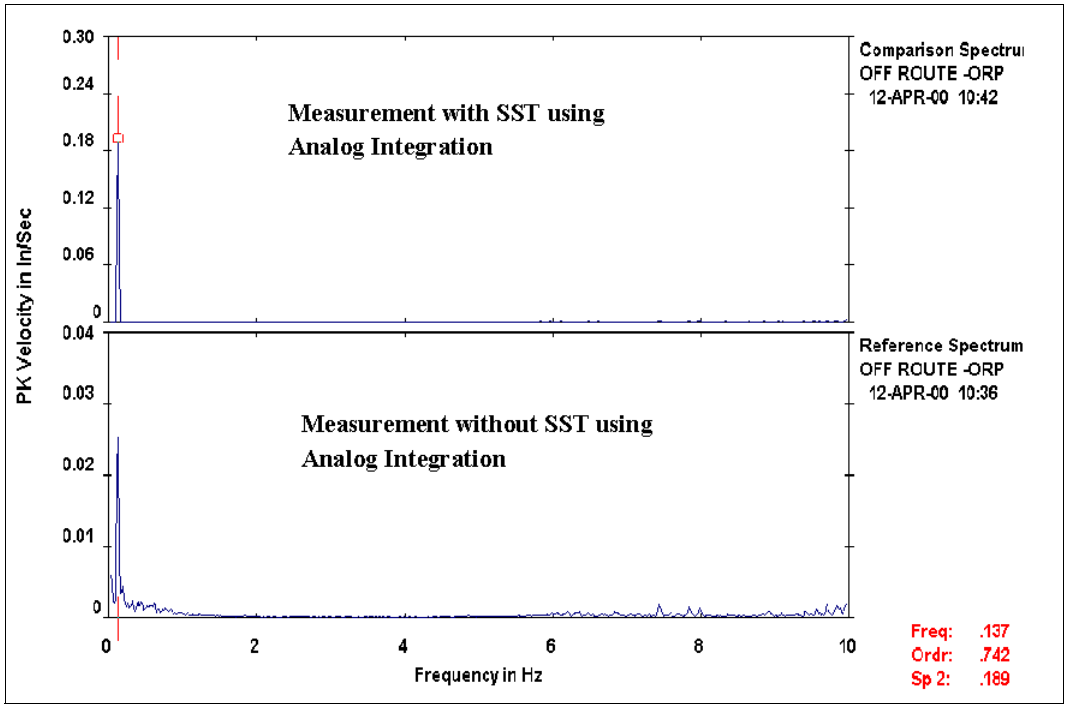
Make Sure that the FS Range is set to Zero – Allowing the analyzer to autorange the incoming signal.


ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : OFF
TRIG LEVEL: 0.00
% PRE TRIG: 0
FS RANGE A: 0.00
FS RANGE B: 0.00
PAGE 2 OF 4 USE PAGE KEYS TO ADVANCE

Press enter to begin the measurement. Remember that the SST correction for deterministic error is not applied until the averaging is complete. The spectrums you see when the averaging is in progress will not look good at the low frequency end until the correction is applied.

The spectral comparison below shows the results of two measurements collected on a slow speed shaft. Both were collected using Analog integration. The top plot used the SST circuit and the bottom plot did not.



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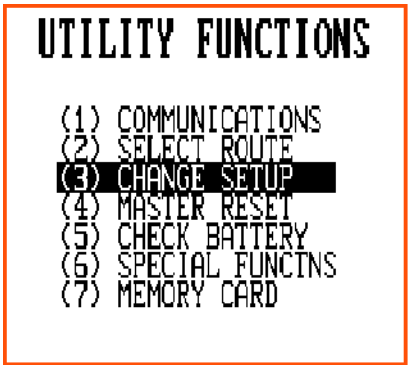
Additional Measurement Considerations

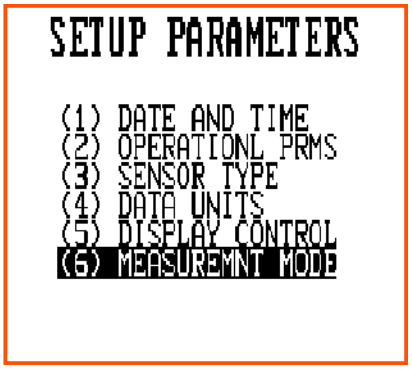
Just two issues must be addressed within the analyzer. Both are found under the UTILITY function key found at the top of the analyzer.

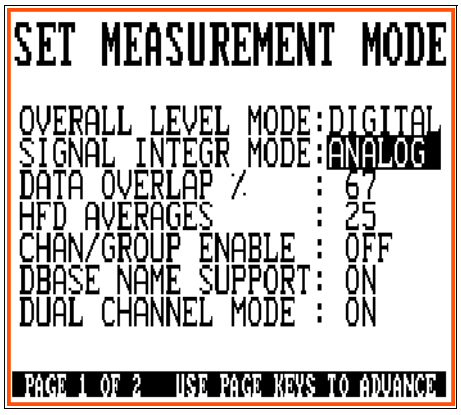
To access the entries discussed here:

- Press **UTILITY**.
- Highlight **(3) Change Setup** and press **Enter**.
- Highlight **(6) Measurement Mode** and press **Enter**.

Signal Integration Mode: Should be set to **ANALOG**. To take advantage of the analog integration's enhancement of the low-frequency data and attenuation of the high-frequency data and to use the SST feature, ANALOG integration is required.






SET MEASUREMENT MODE
OVERALL LEVEL MODE:DIGITAL
SIGNAL INTEGR MODE:ANALOG
DATA OVERLAP %: 67
HFD AVERAGES : 25
CHAN/GROUP ENABLE : OFF
DBASE NAME SUPPORT: ON
DUAL CHANNEL MODE : ON
PAGE 1 OF 2 USE PAGE KEYS TO ADVANCE

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Note

The integration method can be selected from the Route program in MasterTrend if all the points on the roue will use the same integration method. Otherwise, set the Integration Override option to ***NO OVERRIDE*** *and simply control the integration from the analyzer itself.*

Overlap Averaging: Slow speed data has successfully been collected with the overlap averaging set from 0 to 99 percent. Although a higher overlap percentage will reduce the data collection time, any transient signal present in the first or second data sample will continue to be present in each of the later averages. Setting the overlap to 0 percent improves your ability to average away noise in the spectrum. If the background noise is not a problem, then set the overlap averaging higher.

Overlap Examples:

0%	full time records for each average, longer averaging times, averages away noise in measurements
67%	the second and all successive averages use 67% old data and 33% new data, decreases averaging time, increases noise from non-periodic noise
90%	the second and all successive averages use 90% old data and 10% new data, decreases averaging time, increases noise from non-periodic noise

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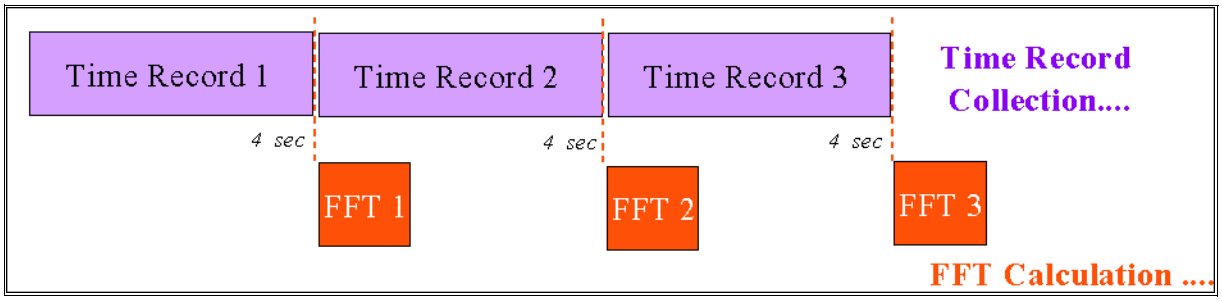
Signal Overlap Explained

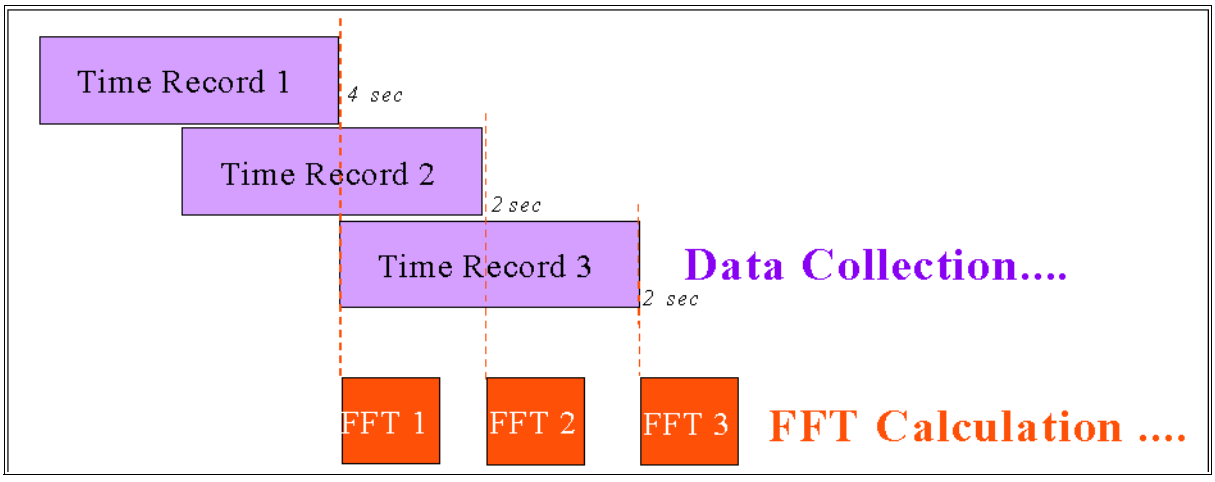
The time required to sample and compute FFT's is determined by the F_{max} and Lines of Resolution. (Time = LOR / F_{max})

The lower the F_{max}, the longer it takes to sample the data. With 0% overlap, the analyzer samples a complete time record for each average. In the 0% overlap example below, the total measurement time for three averages is 12 seconds.



Example of measurements with 0% overlap: 100 Hz, 400 line

By using signal overlap > 0%, the sampling time is decreased. The first time record will be whatever T= LOR / F_{max} has defined. After the first time record has been collected, some old and some new data are used to calculate FFT's for all remaining averages.



Example of measurement with 50% overlap: 100Hz, 400 line

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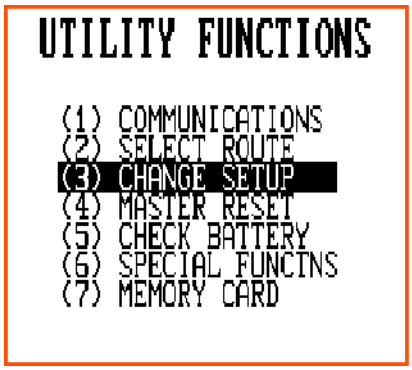
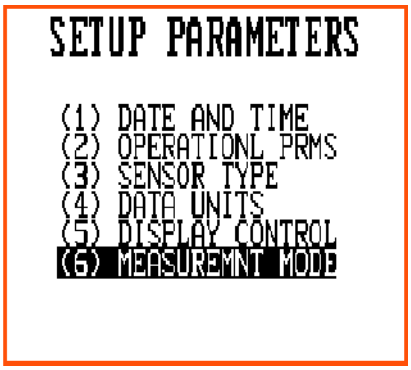
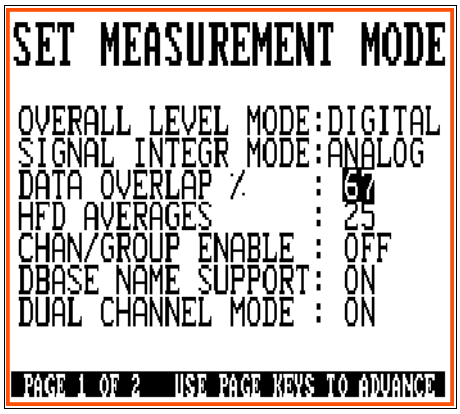
2120 Analyzer Overlap Set-up

The overlap setting on the 2120 analyzer is not controlled by MasterTrend or RBMware. It is controlled on the analyzer on the Utility/Change Setup/Measurement Mode screen. **Whenever the setting is changed, like when doing Peak Hold coastdown measurement, it must be set back to the default 67% – or to the user defined standard setting**.






SET MEASUREMENT MODE
OVERALL LEVEL MODE:DIGITAL
SIGNAL INTEGR MODE:ANALOG
DATA OVERLAP %: 67
HFD AVERAGES: 25
CHAN/GROUP ENABLE: OFF
DBASE NAME SUPPORT: ON
DUAL CHANNEL MODE: ON
PAGE 1 OF 2 USE PAGE KEYS TO ADVANCE

Important Note: When collecting data in the Analyze Mode or the Off-route Mode you will need to address the same MasterTrend/RBMware issues in the analyzer.

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MasterTrend and RBMware Setup

When setting up MasterTrend or RBMware for collecting low-frequency measurement points, a few considerations should be taken into account.

Machine Description

If you are unsure of the machine speed, then select variable speed in order for the measurement point speed to be measured by the analyzer before the data is collected. This will require some sort of tach pulse for the analyzer to read or simply type in the turning speed if it is already known.

Measurement Point Information

A number of items need to be addressed here.

Units Type Code:

0 for Accel converted to Accel

1 for Accel converted to Velocity

Since we will be using analog integration to enhance our vibration measurements, it is recommended to select a **Units Type Code of 1**.

Sensor Sensitivity: The sensor sensitivity should be set based on the sensor you've selected. The recommended sensors should have a sensitivity of nominally **0.5 volts/g**.

Analysis Parameters: The APS is very important as it will control data collection. The details of the APS selections are on the following page.

Sensor Validity Limit: Set the limit range in the range of **0.00001 to 10**. Low frequency data may result in very low vibration levels.

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Analysis Parameter Sets

Spectral Frequency Setup: Should generally be set to Hz or CPM. Setting this based on orders is ok, but, since our turning speeds are so slow, unless we are sure of the turning speed, we may actually miss needed data.

Low Freq. Cond. Limit: Set this value to **zero**. Frequencies below this number are omitted from the overall calculation and from the parameter band calculation. However, even if zero is the selected value, the analyzer omits the first two lines of resolution. Therefore, the true low-frequency cutoff is equal to two times the bandwidth.

Upper Frequency: Consider the turning speed of your machine. Set the F_{max} to 65xTS for a machine with rolling element bearings – may be higher for other types of defects. For slow speed applications, we are considering 600 CPM (10 Hz) as the break point for low-frequency turning speeds.

If our turning speed were 10 Hz, then the F_{max} could be 650 Hz.

$$F_{max} = 65 \times 10\ Hz = 650\ Hz$$

If the turning speed were 0.3 Hz, the F_{max} could be 20 Hz.

$$F_{max} = 65 \times 0.3\ Hz = 19.5\ Hz = 20\ Hz$$

Lower Frequency: The lower frequency is controlled by the Low-Frequency Conditioning Limit for all CSI analyzers except the 2100. The first two lines of resolution will not be seen in the spectral data.

Number of Lines: We will need to select at least **400 lines**. This really boils down to a bandwidth issue. Since the first two lines of resolution are not returned to the analyzer, the bandwidth must be small enough to ensure that no frequency of interest falls within the first two lines of resolution.

For example:

If the turning speed is 0.3 Hz and the F_{max} is set at 20 Hz and 100 lines of resolution are selected, then the bandwidth will be 0.2 Hz/Line.

$$BW = \frac{20\ Hz}{100\ Lines} = 0.2\ \frac{Hz}{Line}$$

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Therefore, the first two lines will include the turning speed frequency.

$$2 * BW = (2\ Lines) * 0.2\ \frac{Hz}{Line} = 0.4\ Hz$$

However, if 800 lines of resolution are used, then the first two lines will be well below the turning speed frequency.

$$BW = \frac{20\ Hz}{800\ Lines} = 0.025\ \frac{Hz}{Line}$$

and

$$2 * BW = (2\ Lines) * 0.025\ \frac{Hz}{Line} = 0.05\ Hz$$

Thus, the turning speed frequency is well above the first two lines of resolution.

Number of Averages: Generally choose **six or more** averages. Fewer averages can be taken and valid data still be gathered, but due to the low vibration levels to be measured and the typically higher background noise levels, more averages are better. Using normal or order track averaging, the more averages collected, the more the random noise levels will decrease. You might find that 12 or more averages are needed to adequately average away the background noise.

SST Control: Set this item to **YES**. The SST control corrects for the deterministic error that occurs with the use of the ANALOG integration method. This feature does not work with the DIGITAL integration selected. The integration may be controlled either at the route level in MasterTrend or at the point level in RBMware.

Number of Analysis Parameters: Set this up depending on the frequency bands that need to be trended.

Analog Pre-Processor: For basic slow speed measurements set to **NO**.

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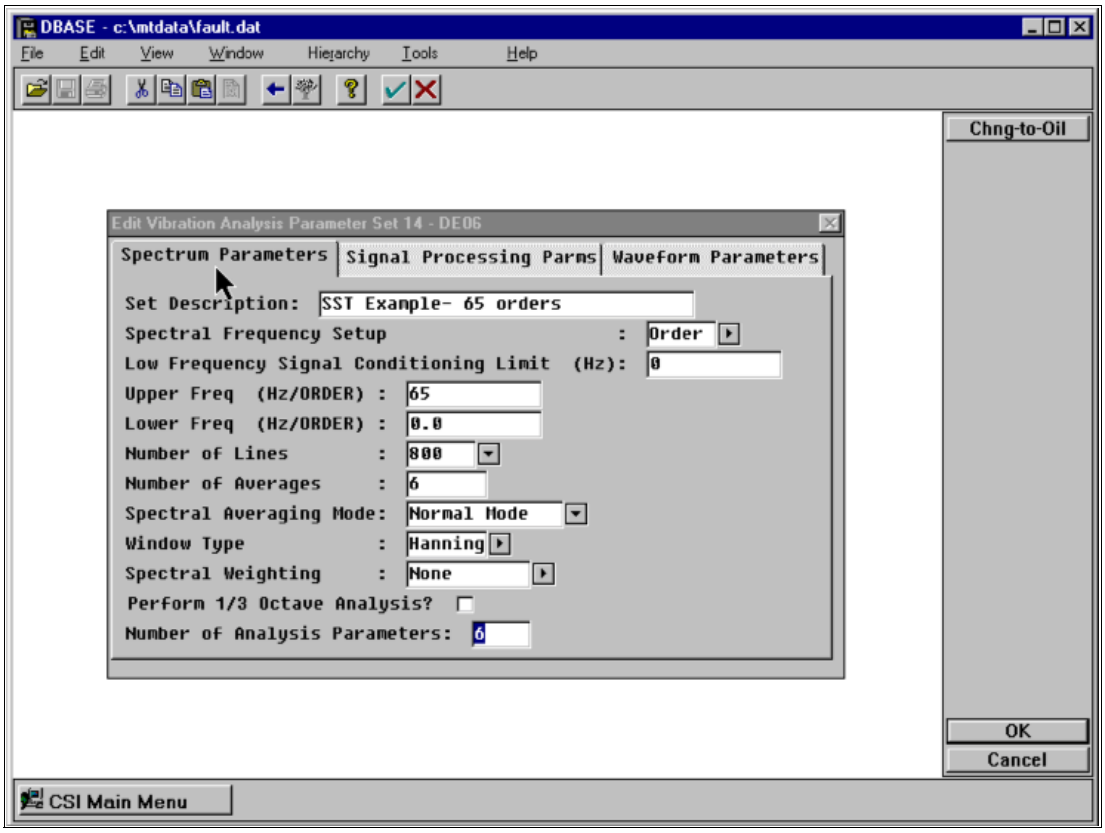
Obtain Special Time Waveform: When using **ANALOG** integration, this feature must be set to **YES *if*** you want to see an acceleration time waveform. It is recommended that the F_{max} be approximately 80 orders of turning speed and the number of points should be at least 1024.

The figure below shows the analysis parameter screen. The SST measurement is set from the center tab **SIGNAL PROCESSING PARAMS**.



MT Example

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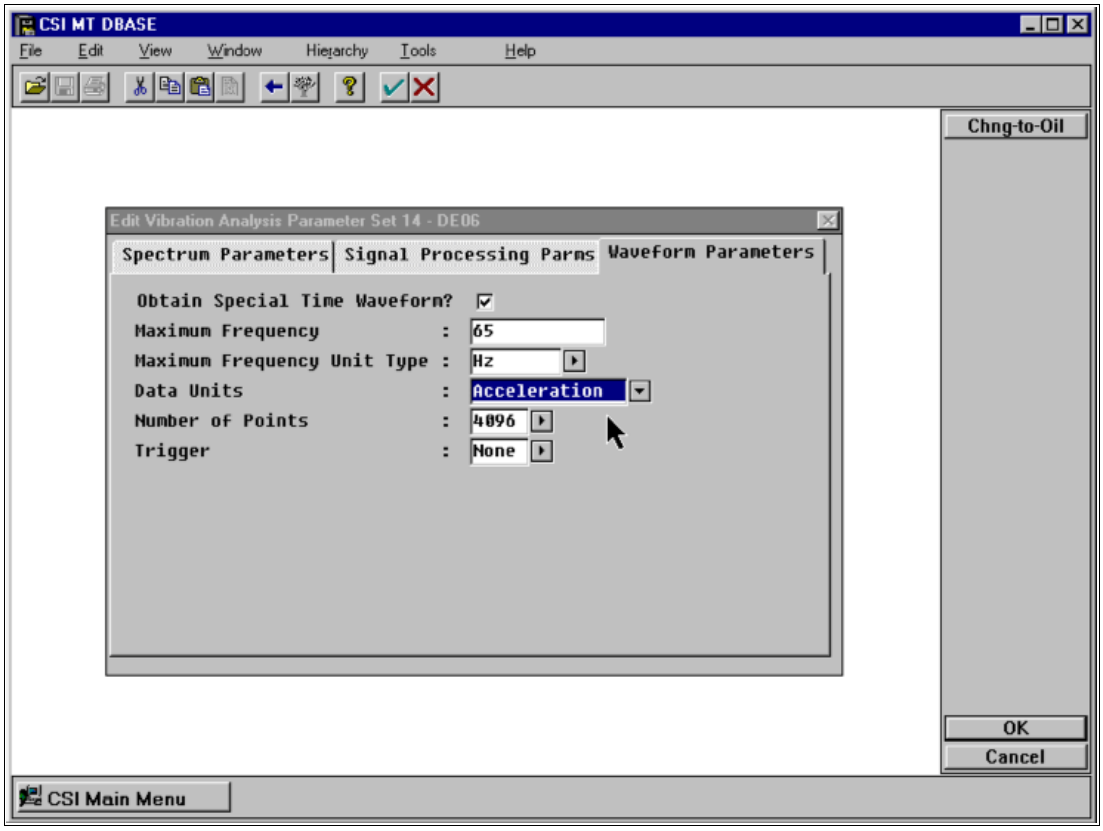
The SST feature requires Analog integration. The resulting time waveform would be in velocity units. If an acceleration waveform is desired, check the SPECIAL TIME WAVEFORM box on the third page of the Analysis Parameter Set. After the initial waveform is measured and the spectrum calculated, the special time waveform will be measured. It will be stored in place of the original waveform.



Click **OK** to build the AP Set into the database. This SST set can now be assigned to slow speed machines in your database.

It is suggested that you build your slow speed machines into special routes to separate them from the normal data routes.

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Low-Frequency Vibration Collection Lab

1. ·· Add a machine to your data base called ORBITER.

2. ·· Add one measurement point. Remember we want to integrate the spectrum from acceleration to velocity. The sensor should be a 0.5 volts per G sensor.

3. ·· Create a parameter set to collect data using the SST method.

4. ·· Create a route using analog integration containing this machine.

5. ·· Download this route and collect data.

6. ·· Go to the Analyze mode and collect additional data.

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Zoom Analysis

Section 5

Objectives

- Understand the best use of the ZOOM feature for high-frequency, high-resolution data collection.
- Collect ZOOM data for detailed high-frequency analysis in the ZOOM lab.

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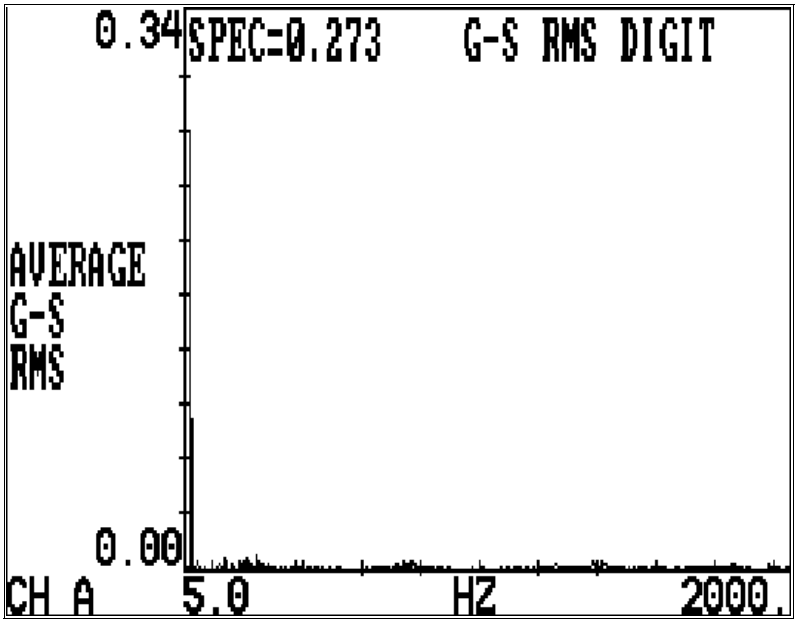
Introduction

This feature can be used to closely examine high-frequency vibration, but it is only available in the 2120 and can only be selected at the 2120. It cannot be selected from MasterTrend. The zoom data can be acquired in the Analyze mode on the 2120 and stored with the route measurement point for examination in MasterTrend later.

ZOOM analysis allows 800 lines between a lower and an upper frequency. The upper and lower frequencies are determined from the available filter selections in the analyzer and from the requirement for 800 line resolution on the zoom. In some cases you can get better spectral resolution by selecting the F_{max} and using 6400 lines of resolution.

Zoom analysis is typically used for higher frequency analysis. The Zoom function will select an upper and a lower filter option that is closest to your specified range and which meets the criteria for 800 lines of resolution in that band. Note that because of the limited selection of filters in the 2120, the analyzer will often default to the predefined values instead of the values you entered.

800 lines = Low cutoff / Bandwidth



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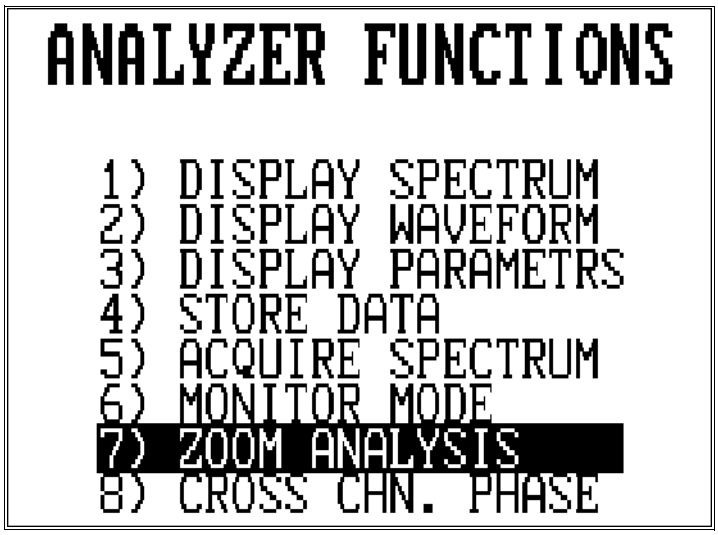
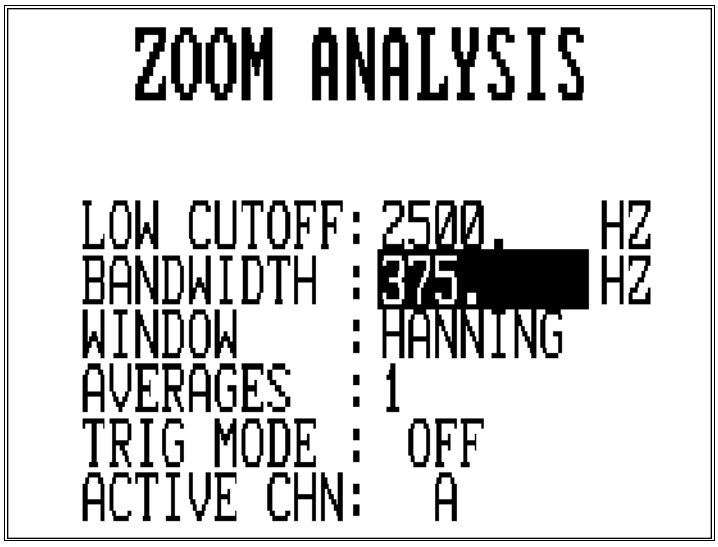
Let's examine some high-frequency data at a greater resolution. Press the **Analyze** key at the top of the 2120 and select **7) ZOOM ANALYSIS**.



Press **Enter** and the following screen will appear in the analyzer. Here we have selected a low frequency of 2500 Hz and an analysis band of 375 Hz. Remember, 800 lines of resolution will be used in this analysis band.



Low Cutoff: This is the F_{min} or starting frequency of the measurement

Bandwidth: Specifies the size of the window (i.e. 200 Hz wide)

Window: Use Hanning for periodic data

Averages: Number of data averages 4-10 recommended

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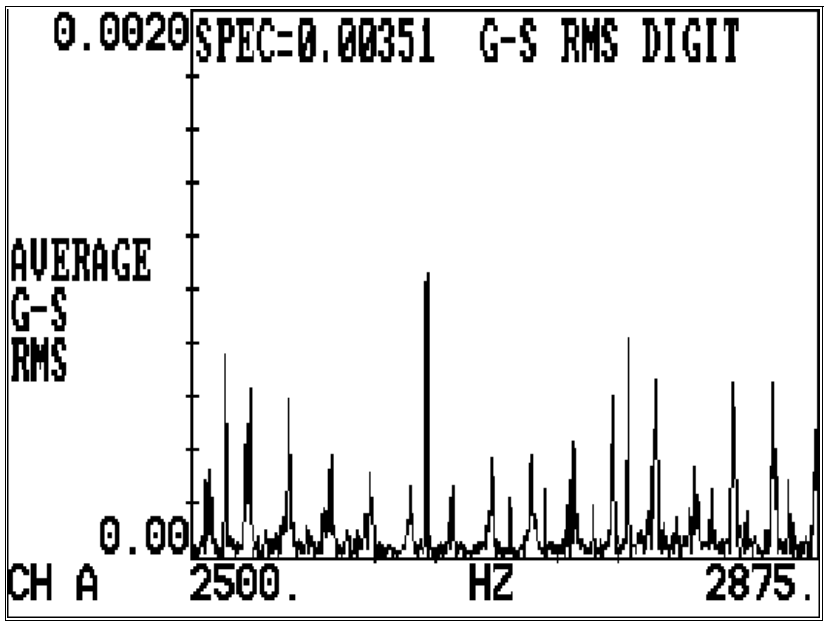
Trig Mode: Allows TACHOMETER triggered data collection

Active Chn: Sets the active channel A, B, or Dual channel

The data collected shows great detail in the high frequencies due to the increased resolution. Although the amplitude is extremely low in this data, notice the separation between the frequencies from 2500 to 2875 Hz.



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Considerations for Zoom Frequency Ranges

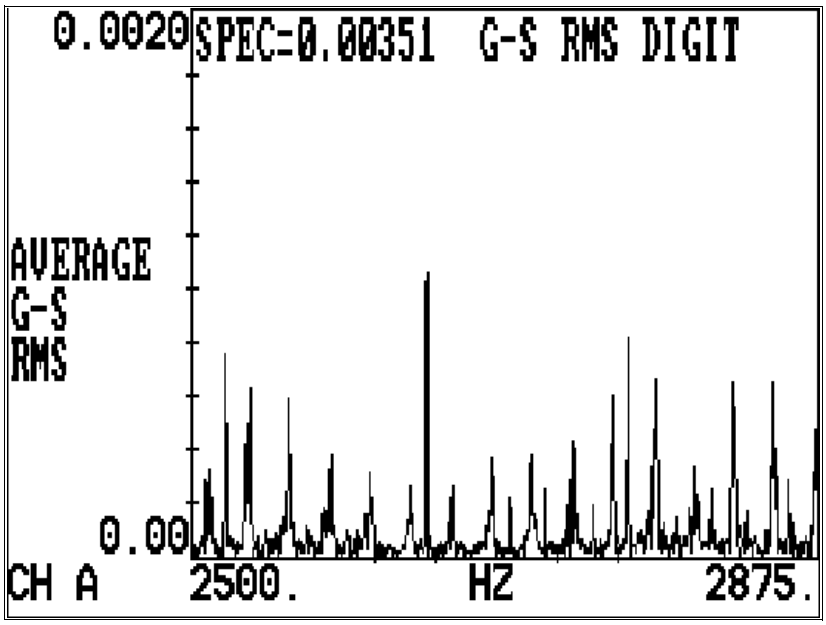
The goal of zoom analysis is to place 800 lines of resolution between a low cutoff frequency and a high cutoff frequency. The difference between the low and high cutoff frequencies will be called the Bandwidth. (Please note that there are other meanings for the term bandwidth used at other times.)

$$\mathbf{BW = F_{max} - F_{min}}$$

For this discussion, the frequency range divided by the number of lines of resolution will be called the Delta Frequency (DF). The DF for normal data collection is found by dividing the F_{max} by the number of lines of resolution. The DF for zoom analysis is found by dividing the bandwidth (defined above) by the 800 lines of resolution used in the zoom process.

$$\mathbf{DF = BW / 800\ lines}$$

In the example below, the LOW cutoff is 2500 Hz and the HIGH cutoff is 2875 Hz. This results in a zoom bandwidth of 375 Hz.



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Zoom Example 1

Zoom analysis is used to look at data at 4300 Hz.

Low Cutoff:	4200 Hz
Bandwidth:	200 Hz
2120 display returns:	4200 - 4400 Hz
Delta Freq:	800 lines or **0.25 Hz / Line**
Best possible resolution without using ZOOM: Delta Freq = 5000 Hz. 6400 Lines = **0.78 Hz / Line**	

In example 1, the Zoom option provided the best resolution.

Zoom Example 2

Zoom analysis is used to look at data at 430 Hz.

Low Cutoff:	420 Hz
Bandwidth:	20 Hz
2120 display returns:	420 - 440 Hz
Delta Freq:	800 lines or **0.025 Hz / Line**
Best possible resolution without using ZOOM: Delta Freq = 500 Hz. 6400 Lines = **0.078 Hz / Line**	

In example 2, the Zoom option provided the best resolution.

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Zoom Example 3

Zoom analysis is used to look at data at 230 Hz.

Low Cutoff:	200 Hz
Bandwidth:	50 Hz
2120 display returns:	200 - 250 Hz
Delta Freq:	800 lines or **0.063 Hz / Line**
Best possible resolution without using ZOOM: Delta Freq = 250 Hz. 6400 Lines = **0.039 Hz / Line**	

In example 3, using 6400 lines of resolution provided the best **result**.

Example 4

Zoom analysis is used to look at data at 23 Hz (1,380 CPM).

Low Cutoff:	20 Hz
Bandwidth:	10 Hz
2120 display returns:	20 - 30 Hz
Delta Freq:	800 lines or **0.013 Hz / Line**
Best possible resolution without using ZOOM: Delta Freq = 250 Hz. 6400 Lines = **0.005 Hz / Line**	

In example 4, using 6400 lines of resolution provided the best **result**.

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ZOOM Data Collection Lab

1. ·· Select the Pump #1 route.

2. ·· Go to the Motor Outboard Horizontal measurement point.

3. ·· Collect data using the ZOOM feature using the same setup shown in this section.

4. ·· Store the spectral data to this measurement point.

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Transient Techniques

Section 6

Objectives

- Understand the factors that control the total amount of time in the time waveform.
- Explain two applications for long time span waveforms.

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Transient Waveform Analysis

Transient analysis can mean different things to different people. Several analysis techniques can be used to examine a machine's vibration over a period of several minutes. One method is to look at data over a long length of time. The other is to use the 2120's downloadable Transient program.

Waveform

Time waveform measurements can be made based on the relationship between the F_{max} and the number of lines of resolution. The maximum length of the waveform will be defined as T_{max}.

$$T_{max} = \frac{Number\ of\ Lines}{F_{max}}$$

The 2120 allows us to collect up to 6400 lines of resolution with a F_{max} as low as 10 Hz. Therefore, it is possible to collect 640 seconds (over 10 minutes) of time data.

Be aware, however, that the waveform will not include any frequencies above 10 Hz. Select the frequencies you want included in the waveform and then select the Lines of Resolution to determine the T_{max} that you want to see.

For example, if the waveform is to include frequencies up to 200 Hz and 6400 lines of resolution in the spectrum are selected, then:

$$T_{max} = \frac{6400}{200} = 32\ seconds$$

Note that a 6400-line spectrum requires that 16,384 points be in the time waveform so that the spectrum can be calculated. The 2120 will collect and display up to 16,384 points, but it will store only 4096 points. For example, in a 32-second waveform, the entire timespan is available for initial analysis after it has been collected. Only the last 8 seconds will be stored for dumping back to MasterTrend.

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The relationship of the waveform sample size to the spectral lines of resolution is shown in the following equation.

$$Sample\ size\ =\ 2.56 \times Number\ of\ Lines\ of\ Resolution$$

Sample Size	Lines of Resolution
256	100
512	200
1024	400
2048	400
4096	1600
8192	3200
16384	6400

Changing the waveform size in the meter from 1024 to 4096 allows longer time waveforms to be stored. Now let's examine some of the data collection principles.

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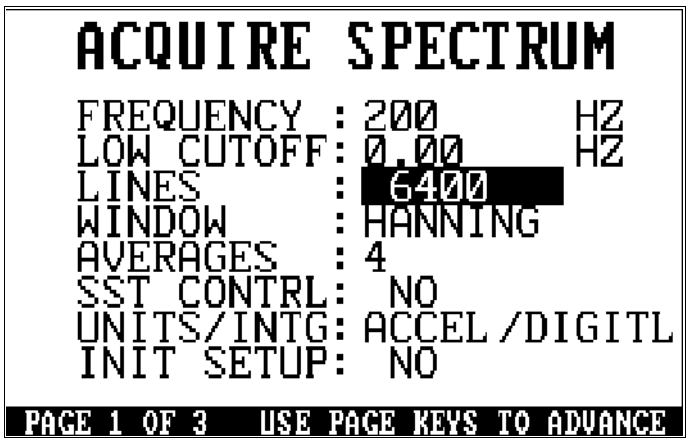
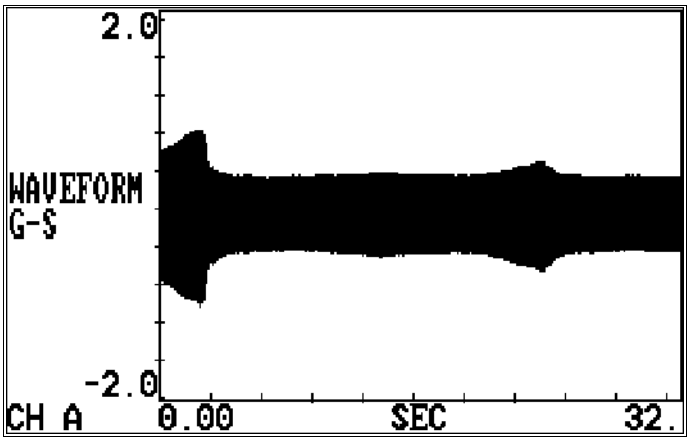
Data will be shown that was collected with the following measurement setup.

This allows a time waveform of 32 seconds to be acquired. T=(6400/200)





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2120 Transient Program- Long Term Data Capture

A powerful analysis tool for the 2120 analyzer is the 2120 Transient Downloadable program. The Transient program will allow the simultaneous data capture of up to 2 channels of data with a 2120-2, two channel analyzer, or a single channel of data when using a standard 2120 analyzer. The size of the waveform and thus the time allowed for data capture is limited only by the size of the PCMCIA memory card used in the 2120. Currently, these cards are available in 1, 2, 4, or 8 Megabyte configurations.

The PeakVue processing option available in the 2120 can be utilized with the Transient program to acquire long time waveform data that can be post processed for analysis of the chosen data segments in the analyzer. The selected Transient data can be displayed as FFT's with resolution ranging from 200 to 6400 lines.

The collection of long time waveforms is very useful in the analysis of machinery that operates under transient loading or operational conditions. Examples of this type of equipment would include Machine tools, compressors, engines, extruders, and any instance where process variables cause variations in the machine's vibration response over time. Another excellent application is on machinery coast-downs or start-ups.

Example:

For our example transient data collection, let's assume that a machine that has high vibration during operation and that it operates intermittently. Bump testing revealed a natural frequency at 100 Hz., but the machine doesn't run continuously, so regular vibration data collection is impractical.

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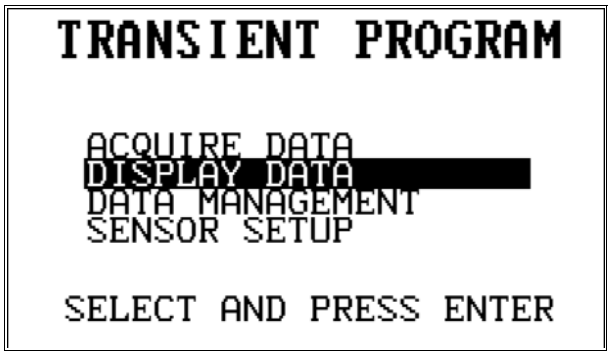
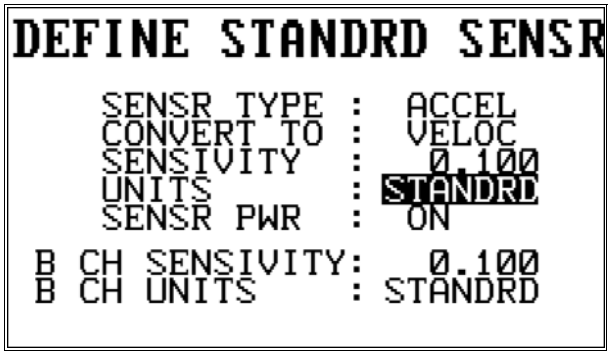
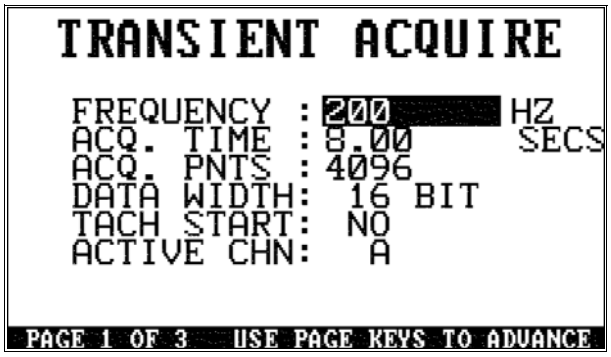
Let's examine the setup for the transient test. The Transient package is a down-loadable program, so press the **Program Select** key on the analyzer to choose the transient program. When the **Enter** key is pressed, the Transient main menu screen is displayed.



Now let's set up our sensor.



With the sensor setup completed, we will setup the data acquisition for our test.


TRANSIENT ACQUIRE
FREQUENCY : 200 HZ
ACQ. TIME : 8.00 SECS
ACQ. PNTS : 4096
DATA WIDTH: 16 BIT
TACH START: NO
ACTIVE CHN: A
PAGE 1 OF 3 USE PAGE KEYS TO ADVANCE

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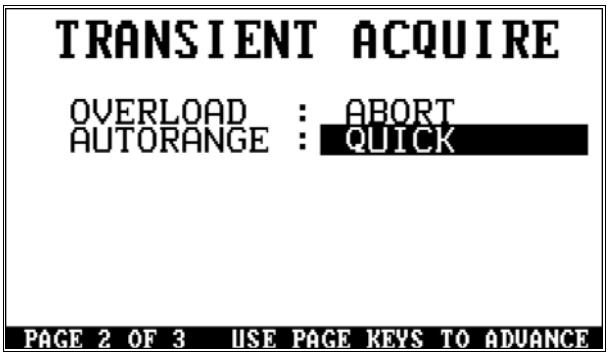
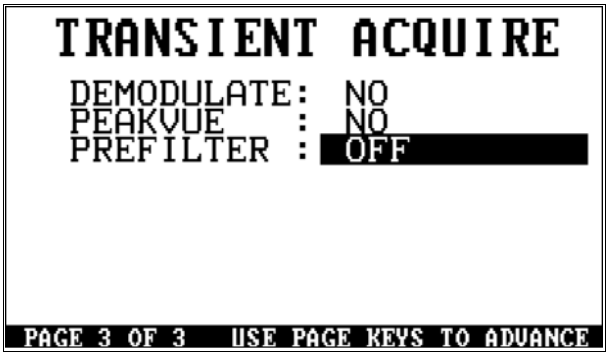
Press the **Page Up** key to set up the second page of Transient Acquire.



For this test, we will use OVERLOAD: ABORT and AUTORANGE: QUICK instead of "Ignore" and "Full Cycle" or "Off" for the overload and autorange options. Press the **Page Up** key to examine page 3 of the setup menu.



Set up as shown above. Press **Enter** to begin the data collection process.

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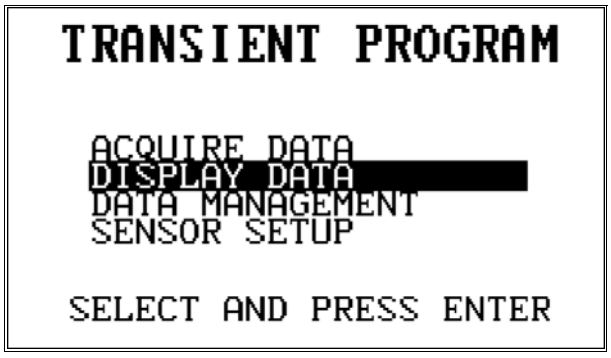
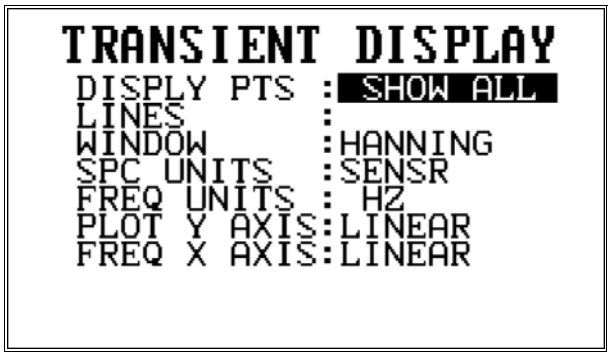
Press **Enter** again to acquire data. Time your data collection to coincide with the transient event on the machine.



After the data collection has completed, the **Transient Program** menu shown above displays. Select **Display Data** and press **Enter**.



Next we will select **SHOW ALL** display Points and press **Enter**.

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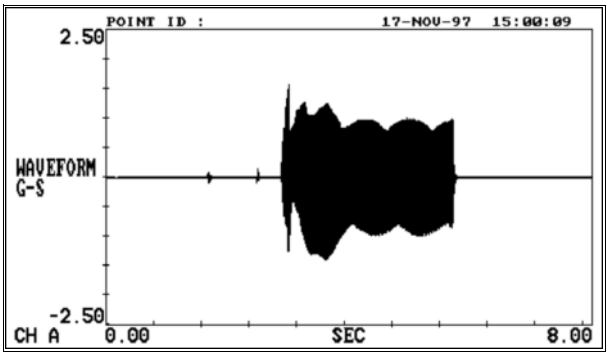
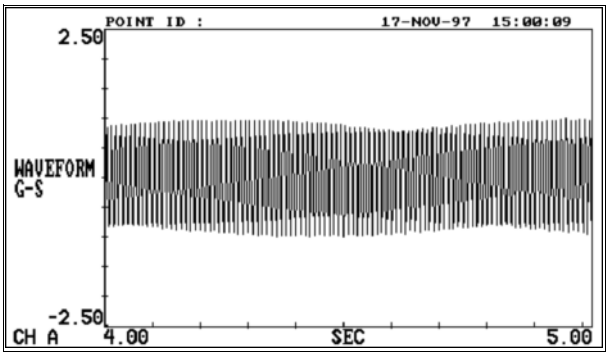
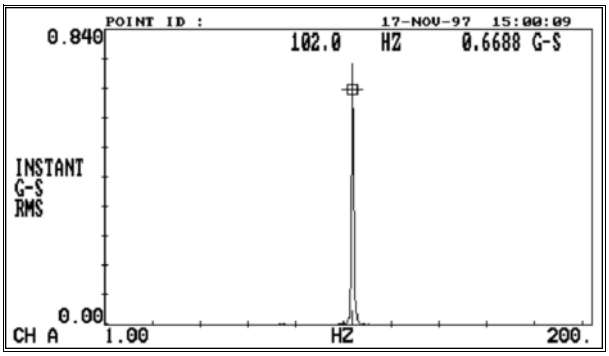


This waveform is a display of all data points taken. Once the data is displayed, press the **Enter** key on the analyzer to return to the display menu. Now select a smaller number of points to be displayed. Press the **Enter** key to return to the waveform display.



Use the **Scroll Up** or **Scroll Down** key to position the data of interest in the display window of the analyzer.



Press the **Show Spectrum** function key to display an FFT of the selected waveform data. The cursor marks the peak at 102 Hz.

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Press enter and select **Data Management** to store the data. Name this data **Example 1**. The data is stored on the PCMCIA card and tagged so it will not be overwritten.

Summary

Long term waveform data collection is an excellent way to view and analyze transient events on your machinery. A method was given to do this on the 2120 analyzer using an extended time waveform and another method was introduced using the Transient downloadable package in the 2120.

The transient package will allow the collection of continuous time waveforms up to the memory limit of the PCMCIA card and post processing to evaluate data for the frequency content and amplitude in a spectrum. The Transient Program will also take 2 channels of data simultaneously if the user has the 2 channel 2120.

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Transient Lab

1. ·· Enter the TRANSIENT program. Setup the sensor to take velocity data from an accelerometer. Select Channel A for input.

2. ·· Set up to collect a machine coastdown.

3. ·· The coastdown will take one minute.

4. ·· Using the principles out lined in this section, choose the Fmax, the acquisition time, autoranging, and overload setting to capture this coastdown.

5. ·· Save this data in the Data Management area for later display.

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Transferring Advanced 2-channel Data to VibPro Software

Objectives

- Learn how to transfer Advanced 2-channel data to VipPro software
- Learn how to export VibPro databases to ME'scope ODS software format

VibPro Software

VibPro is a CSI data transfer and display program. It is used to download Advanced 2-channel and Advanced Transient data from the 2120 analyzer and to view, analyze and print data.

VibPro software is a standalone program that is run off a laptop or desktop computer. For RBMware users, VibPro is one of the analysis tools accessed from the toolbar.

Data that has been collected using either the Advanced 2-channel or Advanced Transient DLP's can be downloaded to VibPro. Data from these DLP's does not download to MasterTrend or RBMware.

To open the program, look for the VibPro icon on the desktop or go to Windows explorer and find the VibPro Subdirectory. Find and double click the VibPro.exe file. When the program comes up, the screen will show a large grey area.

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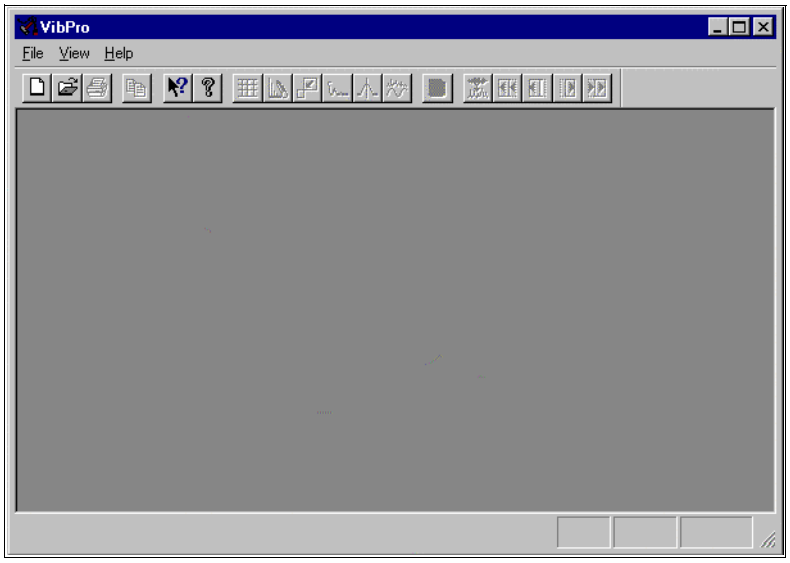
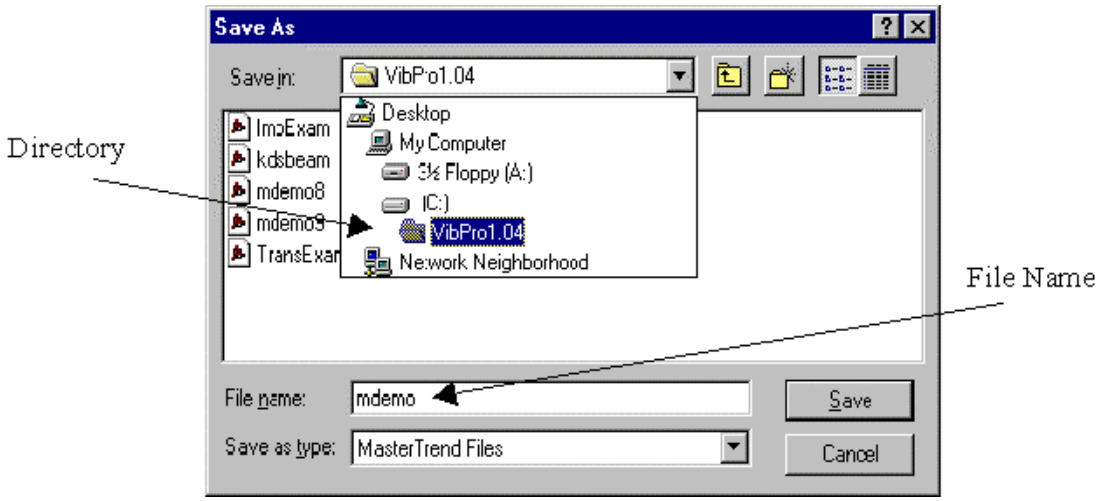


Click on the word **File** at the top of the window then select **New**.

Name the file and select a directory where the data file will be saved. The file name will automatically get a ".dat" extension.



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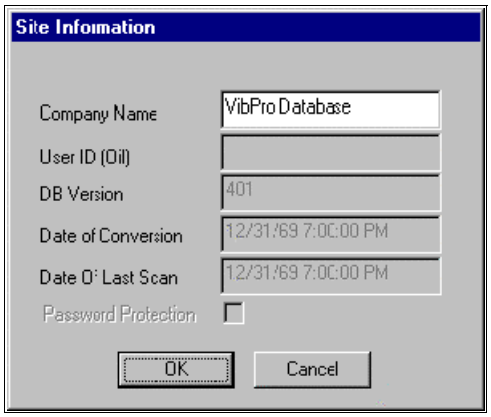
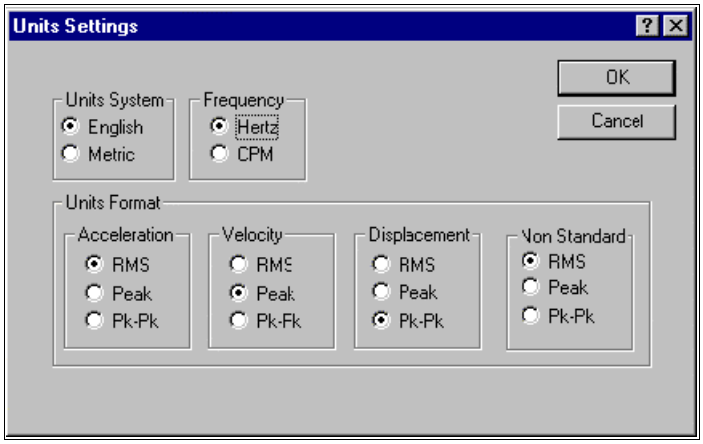
Click "OK" when the "Site Information" window appears (no changes)



Click **OK** when the "Init Settings" window appears (change if desired)



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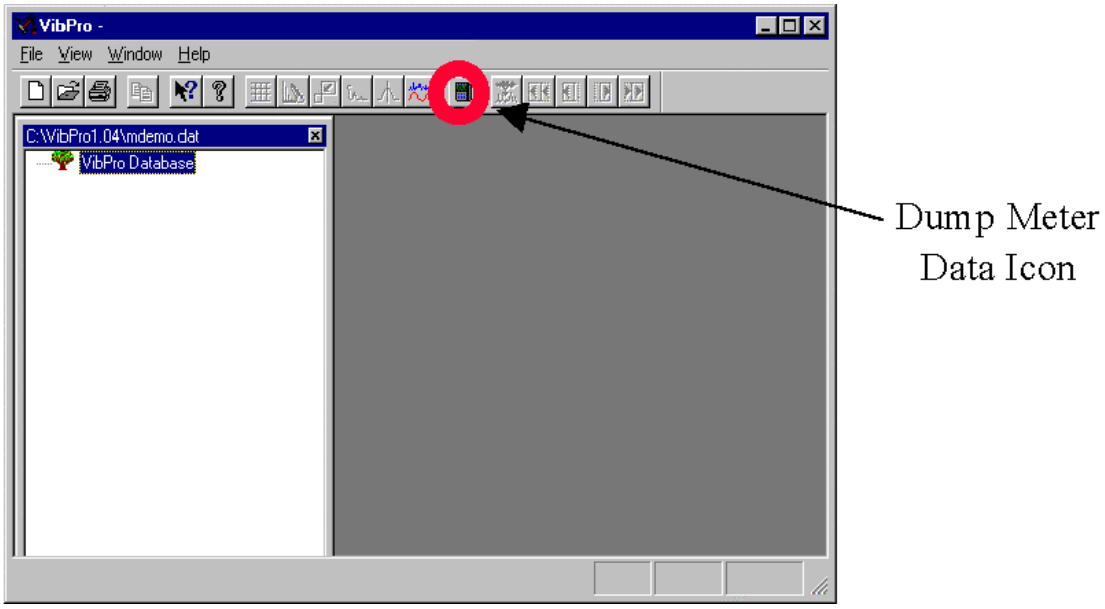
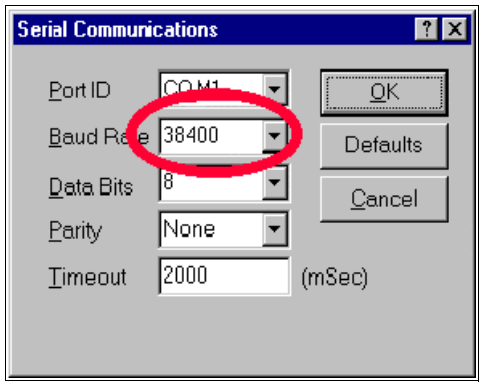
The newly created database appears as a white rectangular box. Click the "Dump Meter Data" icon to the begin data transfer process.



A Serial Communications dialog box opens. Change the communication settings to match the 2120 analyzer's settings. Click OK. The 2120 communication set-up is found on the analyzer by pressing UTILITY, then COMMUNICATIONS, then CONFIGURE PORT.



VibPro Communication Setup

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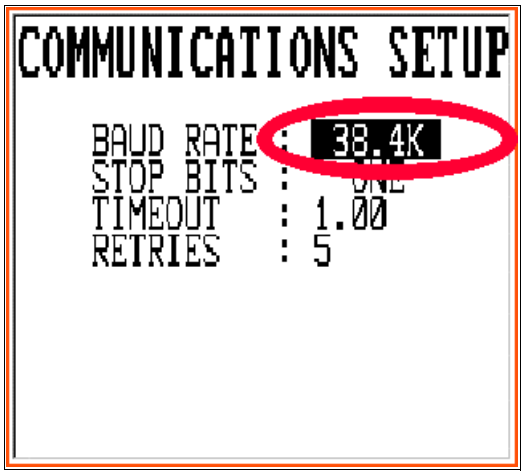
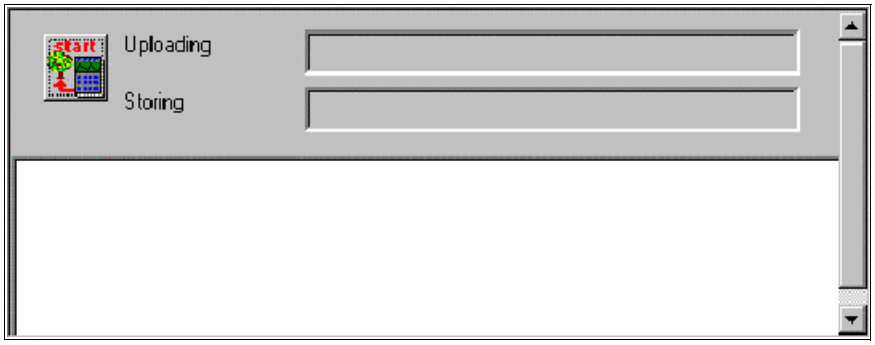


2120 Communication Setup

After clicking "OK" on the VibPro Serial Communication box, the uploading box will appear on the computer screen.



Press "RESET" on the 2120 analyzer to get back to the main Advanced Two-Channel menu.

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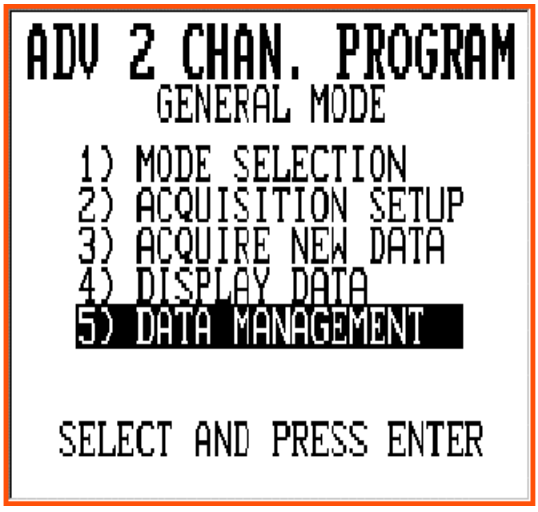
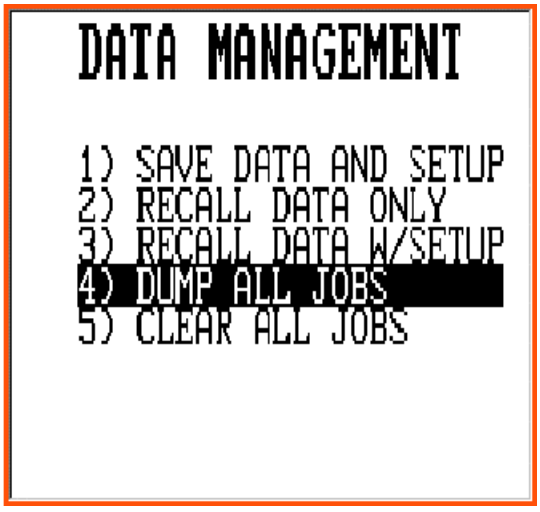
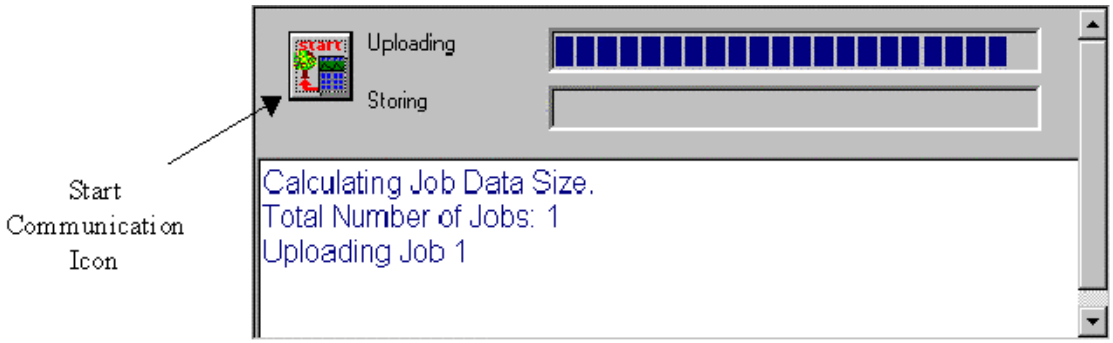
Select **DATA MANAGEMENT** from the menu. Select **DUMP ALL JOBS** from the menu and...

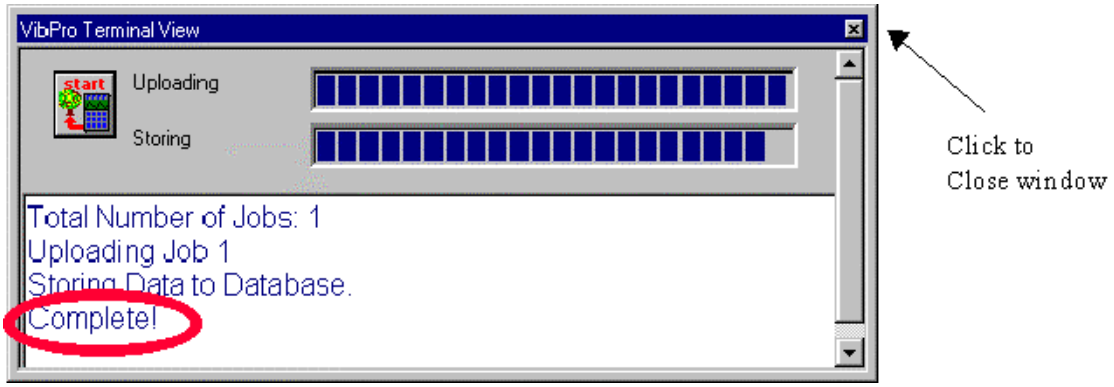




...immediately click the start VibPro communication icon to begin the data transfer.



Wait for the transfer to complete then close out the communications window in VibPro when the "COMPLETE" message appears



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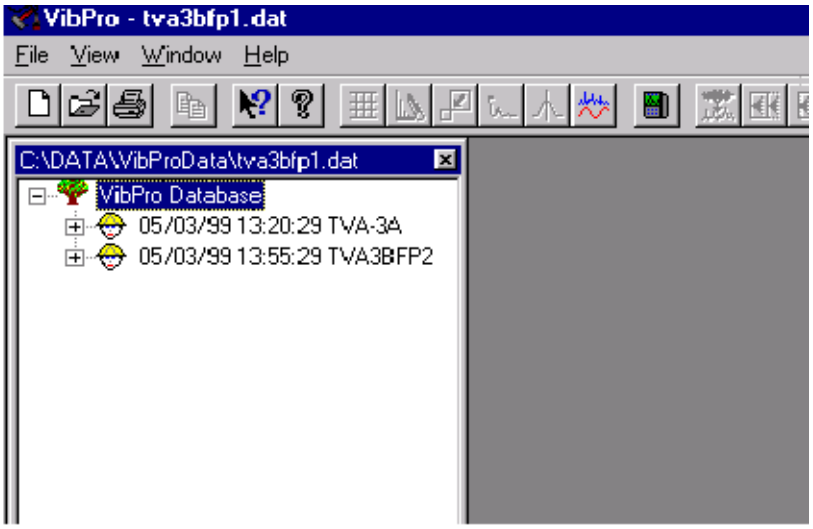
If more measurements will be collected and it is necessary to dump the 2120 to VibPro again, the new data may be dumped to the same VibPro database or to a new VibPro database. Each time data is dumped to a VibPro database, a new job icon will appear in the file window. Job icons are the hard hats in the picture below.

Job Icons:
One for each
download



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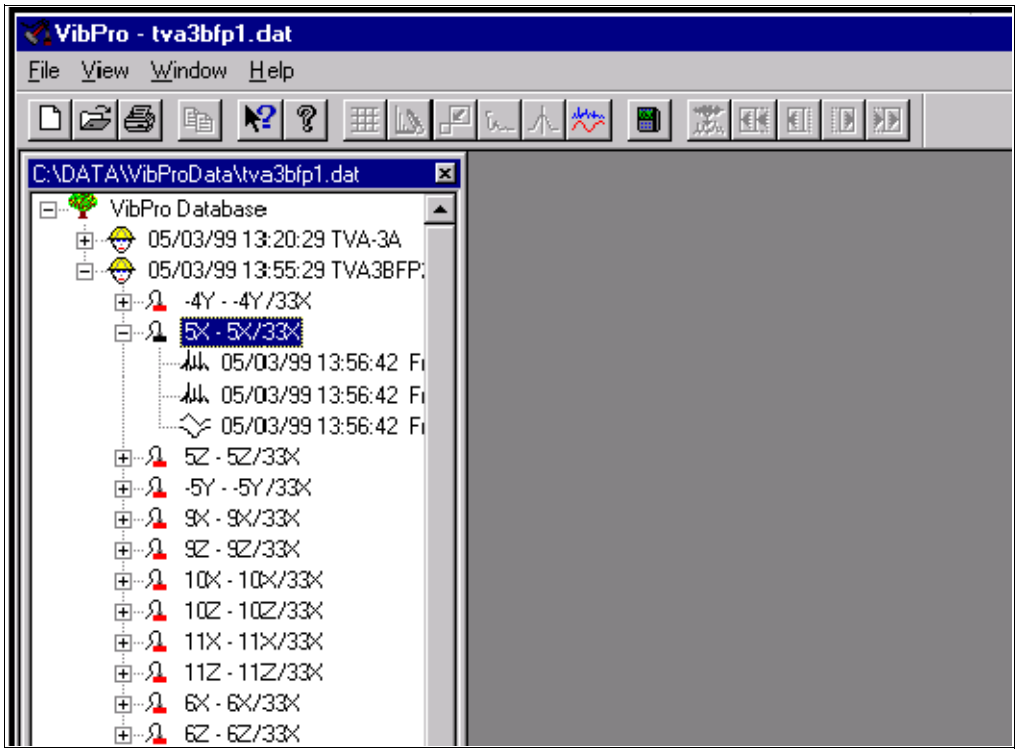
Viewing VibPro Data

It is not necessary to view measurements before or after exporting the data to ME'scope file format.

To look at VibPro data traces, left click on the "+" sign next to a downloaded job and all of the measurements within the job appear. Clicking on a "+" sign next to a measurement shows the data types available for viewing. To view a measurement, double click on one of the data type icons. Viewing VibPro data is not discussed in this course.



To exit ME'scope software, click on the word "file" and choose exit.

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Review

In this section we have discussed how to transfer data collected in the Advanced 2-channel DLP to VibPro software and how to export the database to the ME'scope ODS format.

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Waveform Parameters

Section 7

Objectives

- Understand the capabilities of trending waveform parameters.
- Modify an Analysis Parameter Set and an Alarm Limit Set to best use this feature.

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Introduction

MasterTrend now allows the trending of waveform data as parameter band information. The maximum peak value in the waveform (Max PK), the maximum peak-to-peak value in the waveform (PK-to-PK), and the Crest Factor can all be measured, trended and alarmed.

Measurements of Amplitude			
Pk	=	0 to A	(Peak)
P-P	=	2.0 x A [or A to -A]	(Peak-to-Peak)
RMS	=	0.707 x Pk	(Root Mean Square)
PK	=	1.414 x RMS	
Avg	=	0.637 x Pk	

Note

The conversions above are true only for sine waves.

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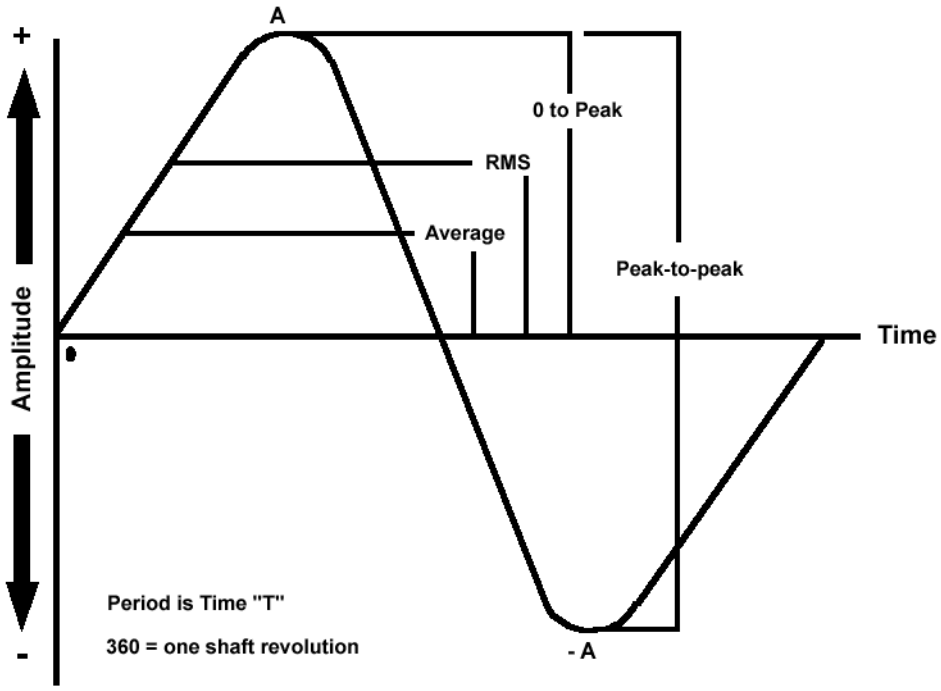
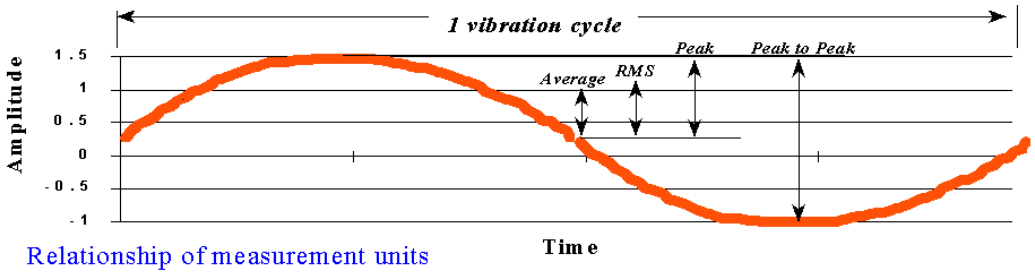
The maximum peak is the value from the reference or zero amplitude to the maximum or minimum amplitude. The peak-to-peak is the value from the maximum positive amplitude to the maximum negative amplitude.



The following chart illustrates the conversion between units.



Relationship of measurement units

multiply by number of / to obtain	Peak to Peak	Peak	RMS	Average
Peak to Peak	1.000	2.000	2.828	3.142
Peak	0.500	1.000	1.414	1.571
RMS	0.354	0.707	1.000	1.111
Average	0.318	0.636	0.900	1.000

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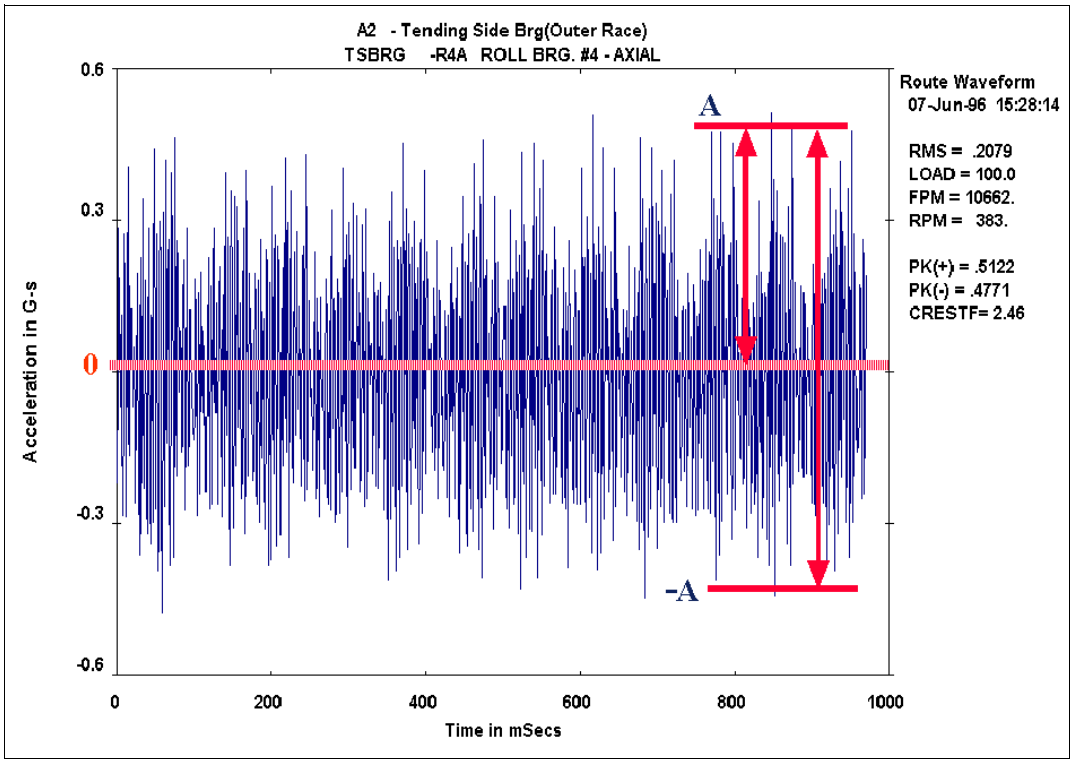

Find the crest factor in the waveform above by dividing the maximum peak value by the RMS value. Crest Factor is a measure of the amount of impacting in the waveform.

To best measure waveform parameters, at least five revolutions of the shaft should be included in the waveform data. This is easily accomplished with a special time waveform selected in the measurement point's Analysis Parameter Set.

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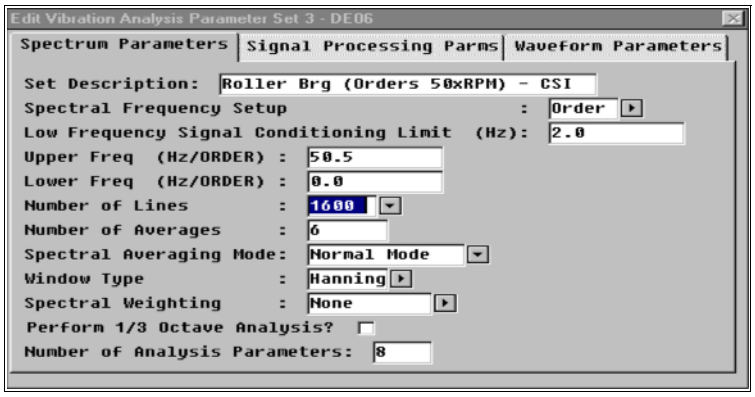
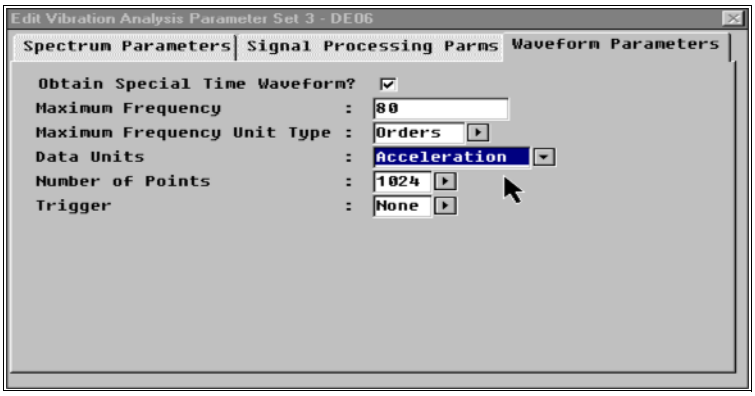
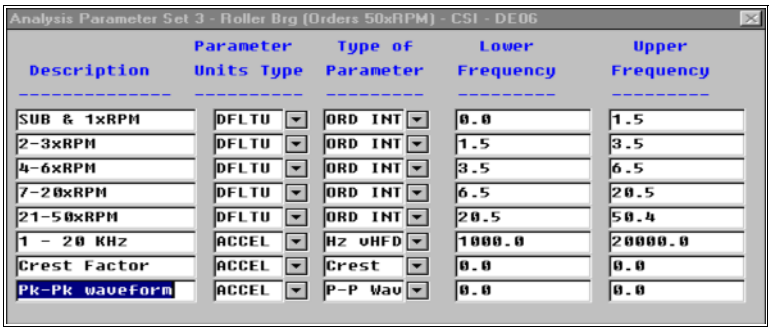
Set the maximum frequency to 80 orders and use 2048 points in the waveform. This will yield a waveform with five shaft revolutions of time data. Generally select the data units to be type one which will give acceleration data. In the remainder of the parameter set, select the waveform parameters to be trended.


Edit Vibration Analysis Parameter Set 3 - DE06
Spectrum Parameters
Signal Processing Parms
Waveform Parameters
Set Description: Roller Brg (Orders 50xRPM) - CSI
Spectral Frequency Setup : Order
Low Frequency Signal Conditioning Limit (Hz): 2.0
Upper Freq (Hz/ORDER) : 50.5
Lower Freq (Hz/ORDER) : 0.0
Number of Lines : 1600
Number of Averages : 6
Spectral Averaging Mode: Normal Mode
Window Type : Hanning
Spectral Weighting : None
Perform 1/3 Octave Analysis?
Number of Analysis Parameters: 8

Add two analysis parameters to the original number. Use eight for this example.


Edit Vibration Analysis Parameter Set 3 - DE06
Spectrum Parameters
Signal Processing Parms
Waveform Parameters
Obtain Special Time Waveform?
Maximum Frequency : 80
Maximum Frequency Unit Type : Orders
Data Units : Acceleration
Number of Points : 1024
Trigger : None

Click on the **Waveform Parameters** tab and fill out as shown.


Analysis Parameter Set 3 - Roller Brg (Orders 50xRPM) - CSI - DE06
Description
Parameter Units Type
Type of Parameter
Lower Frequency
Upper Frequency
SUB & 1xRPM DFLTU ORD INT 0.0 1.5
2-3xRPM DFLTU ORD INT 1.5 3.5
4-6xRPM DFLTU ORD INT 3.5 6.5
7-20xRPM DFLTU ORD INT 6.5 20.5
21-50xRPM DFLTU ORD INT 20.5 50.4
1 - 20 KHz ACCEL Hz vHFD 1000.0 20000.0
Crest Factor ACCEL Crest 0.0 0.0
Pk-Pk waveform ACCEL P-P Wav 0.0 0.0

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Two waveform parameters that work well together are the Peak-to-Peak and the Crest Factor parameters. If a special time waveform is defined, then the waveform amplitude units are set to Default Units. If a special time waveform is not defined, then the actual units of the waveform should be selected C acceleration, velocity or displacement. The upper and lower frequency values are set to zero since waveform data, not frequency bands, are being measured.

An additional use for the special time waveform is that it can be used to save waveform in units of acceleration even if ANALOG integration has been used to convert the acceleration data to velocity. DIGITAL integration is used to convert the spectral data from acceleration to velocity while leaving the waveform data in acceleration units. However, the ANALOG integration method can improve the analyzer's dynamic range over the frequency spectrum and it is needed to use the SST Control feature for lower frequency measurements.

When selecting alarm limits use the following values to start:

Parameter Type	Alert Level	Fault Level
Peak to Peak	2 g's	4 g's
Crest Factor	4	6

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Waveform Parameter Lab

1. ·· Modify the parameter set assigned to the Condensate Pump #1 to include a Peak-to-Peak and a Crest Factor Parameter measurement.

2. ·· Modify the Alarm Limit set assigned to the Condensate Pump #1 to include the Alarm levels discussed in this section.

3. ·· Dump the data currently in the analyzer and then reload the route and recollect the data.

4. ·· Dump the data back to the database after you are done.

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Dual Channel 2120 Features

Section 8

Objectives

- Describe the basic dual channel features of the Dual Channel 2120 Machinery Analyzer.
- Review the MasterTrend configuration for dual point collection
- Measure and discuss Orbits
- Measure and discuss Cross Phase
- Measure and discuss Coherence.

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Overview

The Dual Channel 2120 has several features that make it a valuable analysis tool. The 2120 must be used with the DUAL channel mode enabled to access any of the dual channel features. It can perform orbit analysis and collect cross-channel phase/coherence data on a frequency by frequency basis or at a selected frequency. MasterTrend can be set up to collect two route data points simultaneously and to collect data with the special requirements for orbits.

Orbits can be viewed from any dual channel measurement provided the sensors are placed 90 degrees apart. Typically in an orbit measurement only one shaft revolution is included in the data display. For a 1800-RPM machine speed, simply select a F_{max} at 6000 Hz with 200 lines of resolution for your spectral parameters and then, after the data is collected, the waveform data may be viewed and the orbit may be selected.

If the orbit is to be saved for viewing in MasterTrend, then the orbit must be collected as a dual channel point. That is, the points must have been set up as two points and tied together using the group/channel feature. While two channels of data can be collected using the dual channel mode at the Acquire Spectrum feature of the Analyzer, it cannot be stored to MasterTrend.

Cross Phase and Coherence are very powerful tools that are only possible when using a multi-channel analyzer. The cross phase measurement makes phase analysis possible without using a photo tachometer. Coherence is a cross channel measurement that identifies how related two signals are to each other.

The term ***Dual Channel*** refers to two channels of input signals collected simultaneously. When the two input channels are related mathematically to each other, the measurement is said to be a ***Cross-Channel*** measurement.

Examples of cross-channel measurements include transfer functions, cross phase and coherence.

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Specific uses of the standard features of the 2120-2 (dual channel analyzer) include the following:

1. Dual channel measurement collection in MT or RBMware (*different points, different directions, different parameter sets, different measurement types like regular spectrum & PeakVue*)
2. Split channel measurement collection in MT or RBMware using the 624 split channel adapter (*different measurement types on each channel using one sensor*)
3. Dual channel Measurement Collection in ***Analyze*** or ***Monitor***
4. Orbit measurements in MT, RBMware, Analyze or Monitor mode
5. Cross channel coherence at one specific frequency or over the entire frequency span
6. Cross channel phase at one specific frequency or over the entire frequency span

The capabilities of the 2120-2 analyzer are extended further with the addition of the optional Advanced Two-Channel and Advanced Transient downloadable programs (DLP's).

Advanced Two-Channel DLP

The Advanced Two-Channel DLP provides additional cross channel capability and allows storage of cross channel data to analyzer memory. Any data collected in the Advanced 2-channel DLP is downloaded to VibPro software. VibPro is a stand alone program for Master Trend users (i.e. VibPro databases and MT databases are not compatible). VibPro is an integral part of RBMware (i.e. route data and VibPro data share a common database). The Advanced 2-channel DLP facilitates data collection for Operational Deflection Shapes (ODS). Modal analysis measurements require the use of the Advanced Two-Channel DLP. **Data is stored to the memory location where the Advanced Two-Channel program resides**.

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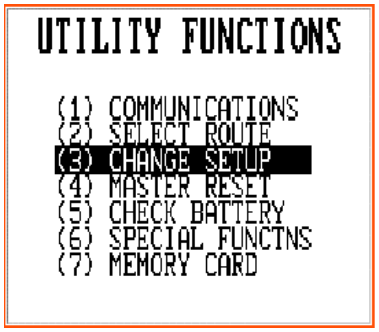
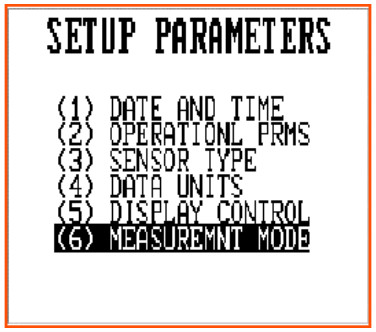
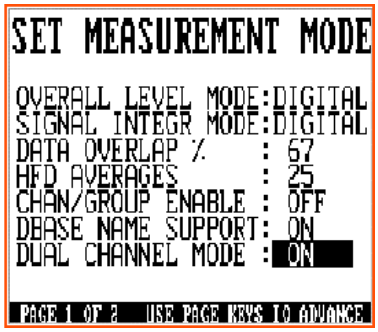
Advanced Transient DLP

The Advanced Transient DLP allows measurement of long digital time waveform captures. The waveform data is stored on the PCMCIA card in the 2120 and downloaded to VibPro for post processing. Advanced Transient is ideal for analyzing random events and start-ups and coast-downs. **Data is stored to the external card regardless of where the Transient program resides**.

Making dual channel measurements on the 2120-2 analyzer requires that the dual channel mode is enabled. Check the following screens to verify that dual channel is enabled on the analyzer.






SET MEASUREMENT MODE
OVERALL LEVEL MODE:DIGITAL
SIGNAL INTEGR MODE:DIGITAL
DATA OVERLAP % : 67
HFD AVERAGES : 25
CHAN/GROUP ENABLE : OFF
DBASE NAME SUPPORT: ON
DUAL CHANNEL MODE : ON
PAGE 1 OF 2 USE PAGE KEYS TO ADVANCE

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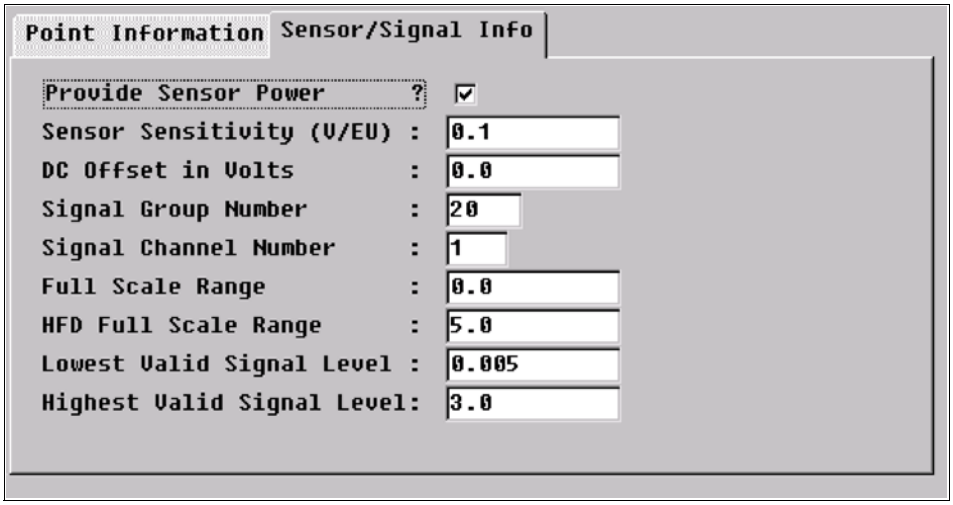
Dual Channel Data Collection in MT

Once the analyzer is configured to collect dual channel data, Master Trend and RBMware routes may be set up or changed to measure two simultaneous signals. Dual point route collection requires a simple change to the **Sensor/Signal Info** tab of a measurement point screen. To group two measurement points together in a machine, give both points the same signal group number. The signal group number must be equal to or higher than 20. Give one of the measurement point a signal channel number of **1** and make the second point **2**.

In the example below, the motor outboard horizontal point is given a group number of 20 and signal channel number 1. This point is to be grouped with the motor outboard vertical measurement point. The sensor set-up screen for the vertical position will have the same group number and a channel number of **2**.


Point Information
Sensor/Signal Info
Provide Sensor Power ?
Sensor Sensitivity (V/EU) : 0.1
DC Offset in Volts : 0.0
Signal Group Number : 20
Signal Channel Number : 1
Full Scale Range : 0.0
HFD Full Scale Range : 5.0
Lowest Valid Signal Level : 0.005
Highest Valid Signal Level: 3.0

If the motor inboard horizontal and vertical positions are also to be grouped, those points would have a different group number above 20 (*21 could be used*). The signal channel numbers will always be either 1 or 2.

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Existing single point collection routes need only to be modified like the example above to become dual point collection routes. The 2120-2 screen identifies route points as dual points. An example is shown below. When the enter button is pressed, both the horizontal and vertical measurements will be made simultaneously.

Dual point route collection is not limited to the same kind of measurement for each channel. Channel 1 could have a different F_{max} or parameter set than channel 2. One of the two channels might be a PeakVue or Demodulation measurement.

A single accelerometer may be used in conjunction with the model 624, split signal adapter, to measure two different signals from the same accelerometer. The model 624 adapter splits the input from a single accelerometer and sends it to both channels of the 2120 analyzer. One use for the adapter is to place a single accelerometer on a bearing and simultaneously measure a regular route spectrum and a PeakVue spectrum.

Refer to technote #98-01063 for additional details about dual point collection.

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Dual Channel Data Collection in Monitor and Acquire

All that is necessary to collect dual channel data using the Monitor or Acquire programs on the 2120-2 analyzer is to enable both channels on the set-up screen. The choices in the active channel field are "A", "B" or "Dual". An example of the Acquire Spectrum set-up screen for dual channel collection is shown below.

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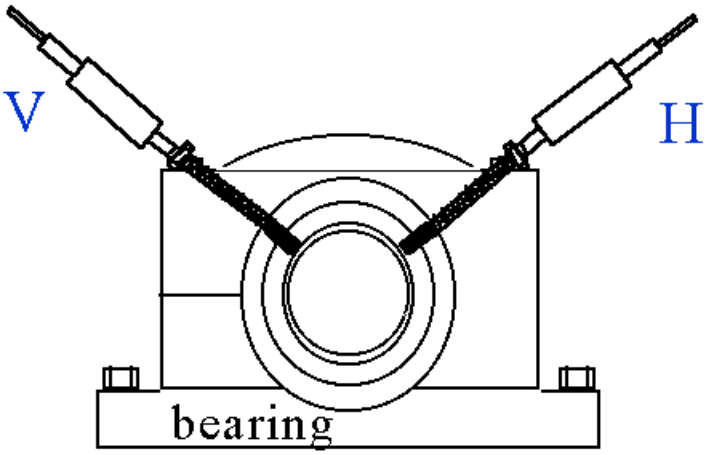
Orbit Measurements

In vibration analysis, an ***orbit plot*** is the trace of the relative movement of the centerline of a rotating shaft within the clearance of a plain (journal) bearing. Orbit plots are used to detect and investigate abnormal movements of the shaft in a bearing. This movement often characterizes a developing fault, such as unbalance, misalignment, bearing rub, shaft or rotor whirl, etc. Two probes mounted at 90 degrees to each other are required for making shaft orbits. Shaft orbits are typically made with displacement probes such as proximity probes.



API 670 (1986) prox probe mounting convention

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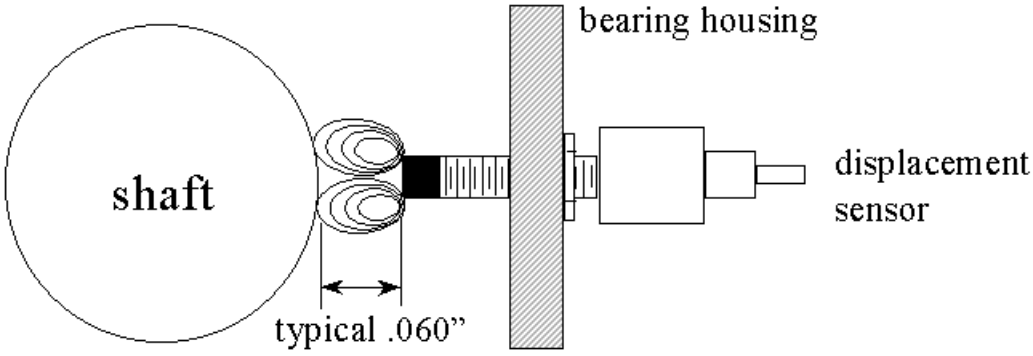
A proximity probe emits an eddy current field at the tip of the probe. The probe is spaced away from the rotating shaft by a small amount (typically 0.060". The probe's output voltage is proportional to the gap.



Orbit measurements can also be made using case mounted accelerometers on a bearing housing. An orbit, measured with two accelerometers mounted 90 degrees to each other on a motor housing, indicates the vibrational pattern of the motor housing.

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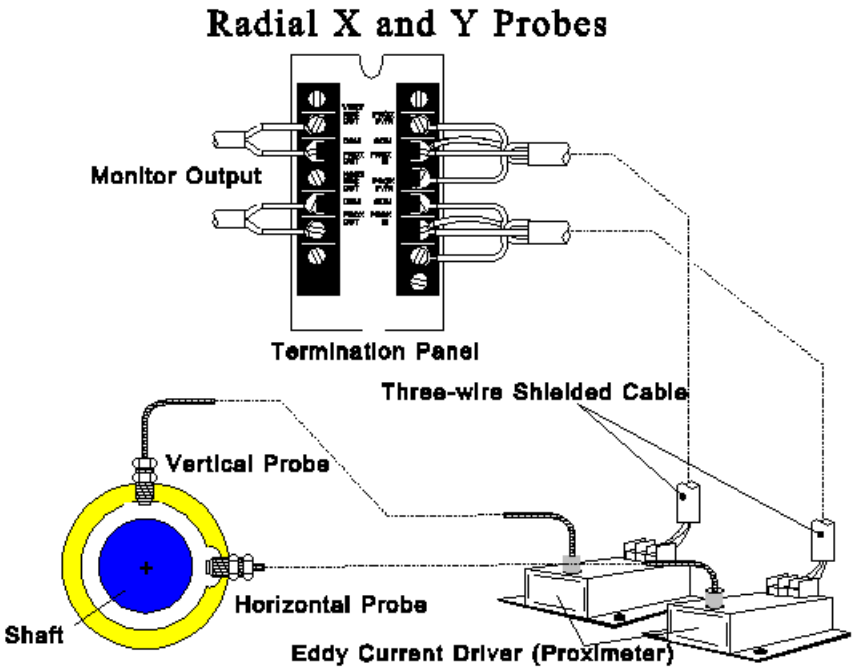
Typically, the measurement is made by using the output of two non-contacting displacement transducers (proximity probes). According to the American Petroleum Institute (API) Standard 610, the first probe to sense the vibratory energy is considered the vertical probe, ***Y***. The trailing probe is considered to be the horizontal, *X*. The probes must be mounted 90 degrees from each other. This mounting may be a true vertical and horizontal relationship as shown below, or in an ***X*** and ***Y*** configuration 45 degrees on both sides of true vertical. Typically, the two signals are taken as outputs from a supervisory panel and fed into the inputs of an oscilloscope. The signals produce a trace on the screen corresponding to the total shaft motion, which is the orbit of the shaft in the bearing.



A tachometer signal is not required for an orbit. If a tachometer signal is present, the pulse provides both frequency and phase information. On an oscilloscope display, a reference pulse appears as a bright or blank spot on the orbit plot. On the 2120, phase is indicated as a line radiating out from the center of the orbit.

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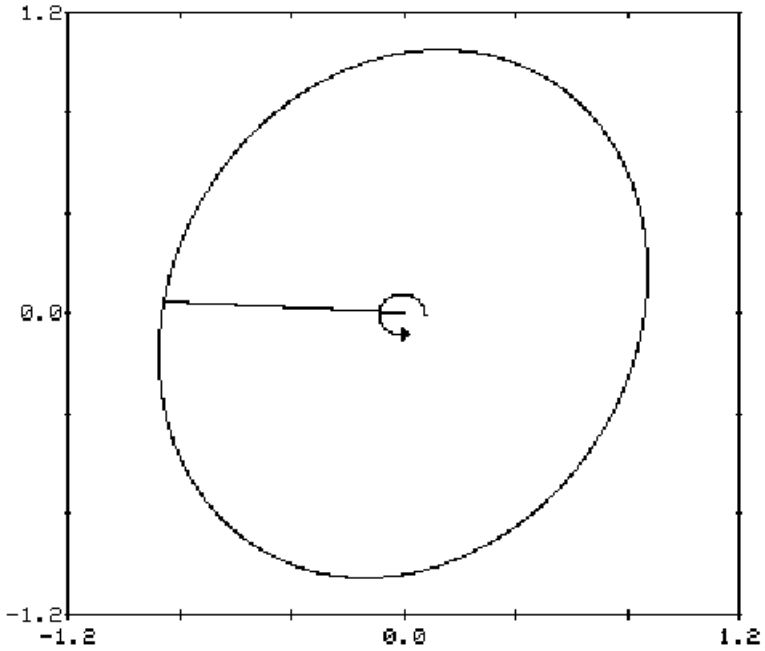
An unfiltered orbit refers to vibration energy at all frequencies measured in the set-up. A filtered orbit is a trace of vibration at one particular frequency (*usually 1x or harmonic*). A sample orbit plot is shown below.



In the 2120-2 analyzer, orbit plots can be measured four different ways:

1. ·· Analyze / Monitor Waveform

2. ·· Analyze / Acquire Spectrum

3. ·· Analyze / Monitor Orbit

4. ·· As part of a predictive route.

The Analyze, Monitor Orbits feature was added in 7.43 firmware. It is easy-to-use function for measuring orbits. Orbit measurements from Monitor Waveform and Acquire Spectrum require some calculation in order to set up the 2120-2 analyzer. These two methods are discussed first.

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Measuring Orbits using Analyze Monitor WF or Acquire Spectrum

Orbit measurements using the Analyze / Monitor Waveform or Analyze / Acquire Spectrum functions is a three-step process involving some calculation. The steps are outlined below.

STEP 1

Calculate the time for one revolution of the shaft

The time (T) to complete one rotation of the shaft is calculated by taking the inverse of the shaft frequency (F)-- in Hertz.

T = 1 / F

Example:

Shaft speed = 1800 rpm = 30 Hertz

T = 1 / 30 = 0.033 seconds

STEP 2

Calculate the lines of resolution needed

The only consideration in choosing the number of lines of resolution for the measurement is to have at least one sample per degree of shaft rotation. There really is no calculation required here because 200 lines of resolution will always provide enough samples per rotation. The number of samples is the product of 2.56 times the lines of resolution. As demonstrated below, 100 lines results in too few samples per revolution and anything higher than 200 lines is overkill.

 # Samples = 2.56 * LOR

A 100 line spectrum has 2.56 * 100 = 256 samples (fewer than 1 per degree)

A 200 line spectrum has 2.56 * 200 = 512 samples (more than 1 per degree)

A 400 line spectrum has 2.56 * 400 = 1024 samples (much more than needed)

For orbit measurements on the 2120-2 analyzer, **always use 200 lines of resolution**.

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STEP 3

Calculate the F_{max} needed.

Set up on a 2120, for the most part, requires the user to enter the F_{max} and lines of resolution desired. The F_{max} for orbit measurements is calculated by dividing the LOR by the time (T) for one revolution.

$$\mathbf{F_{max} = LOR / T}$$

Example:

$$\mathbf{T = 0.033 \text{ and } LOR = 200}$$

$$\mathbf{F_{max} = 200 / 0.033 = 6000 \text{ Hertz}}$$

The frequency span needed to generate an orbit for a 20 Hertz shaft is 6000 Hz.

Some analyzers allow the user to input a sample rate instead of a frequency span. CSI analyzers do not. To calculate the required sample rate, multiply the F_{max} using the formula above by the Nyquist rate which is 2.56.

$$\mathbf{\text{Sample Rate} = 2.56 * F_{max}}$$

Example:

$$\mathbf{F_{max} = 6000 \text{ Hz.}}$$

$$\mathbf{\text{Sample Rate} = 2.56 * 6000 \text{ Hertz} = 15{,}360}$$

A sample rate of 15,360 samples per second is required to generate an orbit of a shaft rotating at 30 Hertz.

With the calculations out of the way, the 2120-2 analyzer can now be set up to measure orbits. Route orbit measurements can be made by configuring Master-Trend for dual point collection. Dual point collection was discussed at the beginning of this chapter.

Orbits are also measured using the Analyze feature of the 2120-2 analyzer. The Analyze/Monitor Waveform feature measures live orbit data. The Analyze, Acquire Spectrum feature results in an orbit display only after the acquisition has completed. Both of these methods measure unfiltered orbits.

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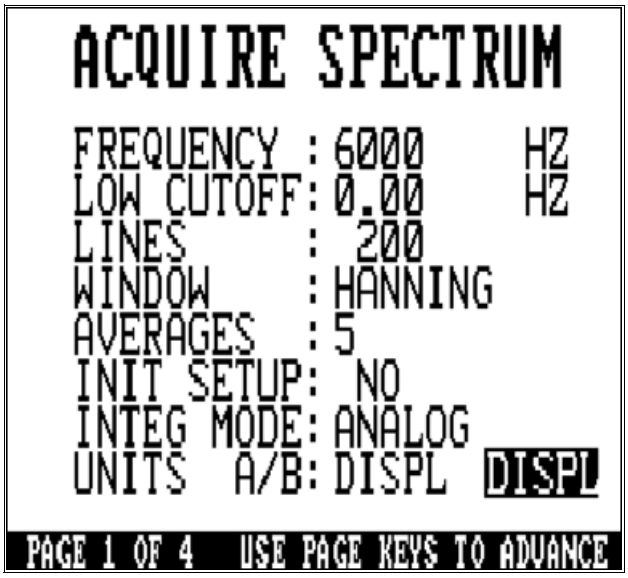
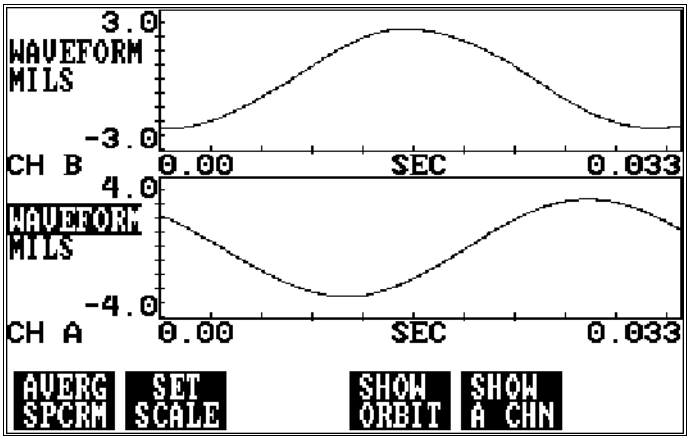
Orbit Measurement in Analyze/Acquire Spectrum

To make an orbit measurement in the Acquire Spectrum function of the 2120 analyzer, set-up the acquisition screen as shown below. Use velocity or displacement for best results. Once the measurement has completed, press F1 to view the time waveforms.



Notice that the waveform length is 0.033 seconds ñ the time calculated for one shaft rotation at 1800 rpm. Press the F4 key to display the orbit.



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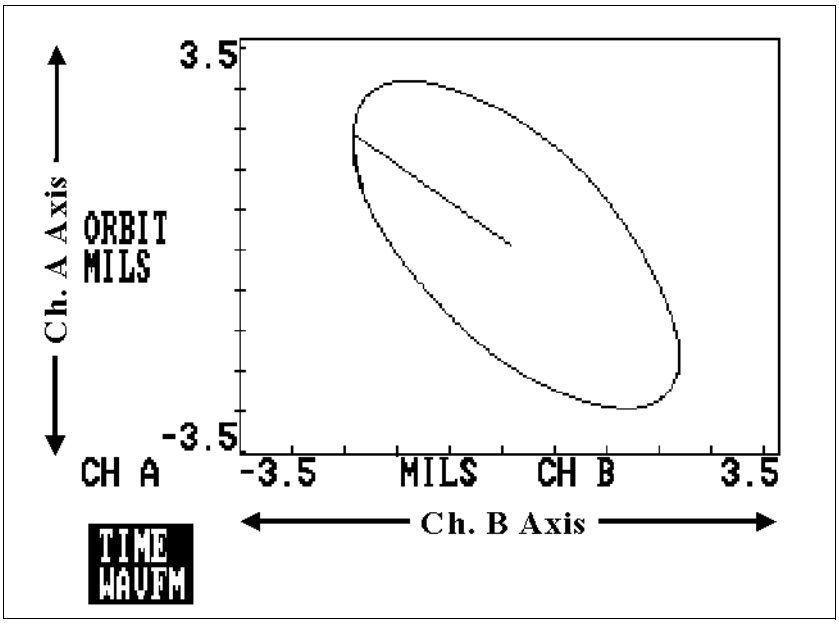
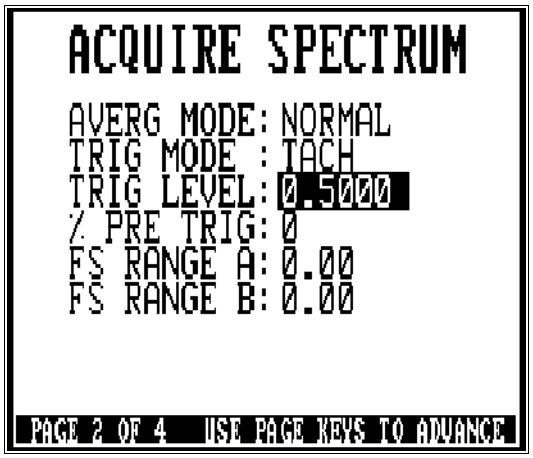


The scaling on the "X" and "Y" axes of the orbit plot should always be the same (by default). The horizontal axis is Channel B and the vertical axis is channel A. Analyzing the orbit's shape holds the clue for diagnosing defects. The phase mark is not real unless a tachometer was used.

If a tachometer signal is available, set-up the trigger mode screen for TACH trigger with an appropriate trigger level and measure the orbit again.


ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : TACH
TRIG LEVEL: 0.5000
% PRE TRIG: 0
FS RANGE A: 0.00
FS RANGE B: 0.00
PAGE 2 OF 4 USE PAGE KEYS TO ADVANCE

Orbits, measured in Analyze/Acquire Spectrum mode can be saved to analyzer memory as long as a route is present on the analyzer.

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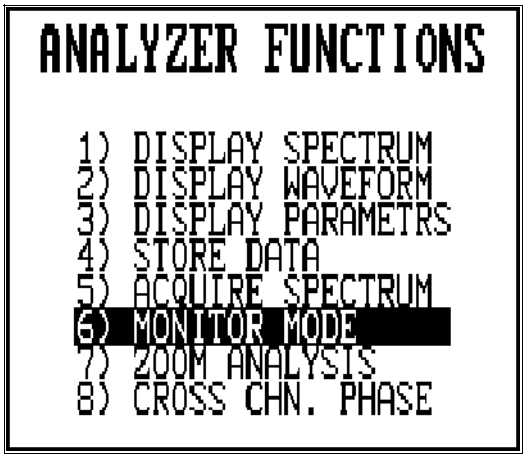
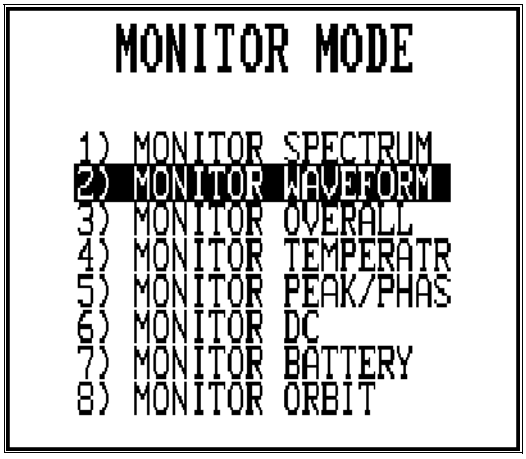
The Analyze/Acquire Spectrum method of measuring orbits does not produce an orbit until the measurement has completed. To measure and display a live orbit, use the Analyze, Monitor Waveform function.

Orbit Measurement in Analyze/Monitor Waveform

Set-up the measurement screen with the frequency span and lines of resolution required. When the measurement begins and the waveforms are displayed, press F4 to display the live orbit. If the phase is steady, the tach line will be stable.





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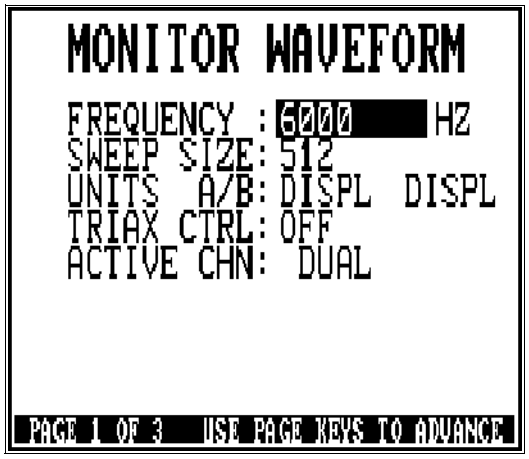
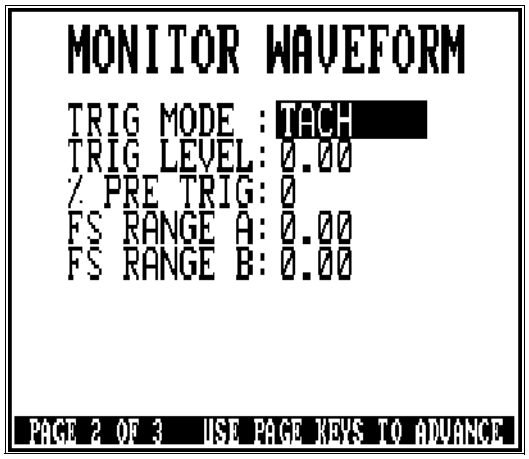

MONITOR WAVEFORM
FREQUENCY : 5000 HZ
SWEEP SIZE: 512
UNITS A/B: DISPL DISPL
TRIAX CTRL: OFF
ACTIVE CHN: DUAL
PAGE 1 OF 3 USE PAGE KEYS TO ADVANCE

A tachometer is not required. If one is used, an accurate phase mark will be displayed.



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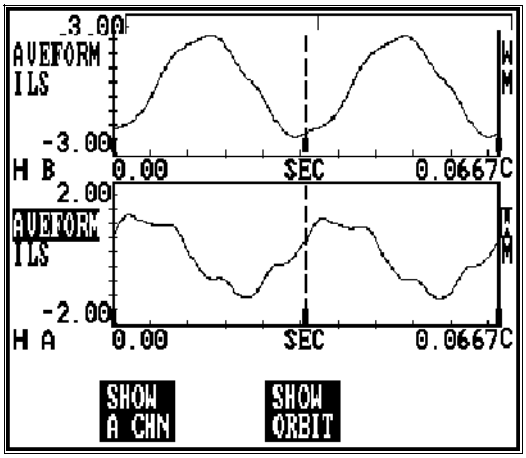
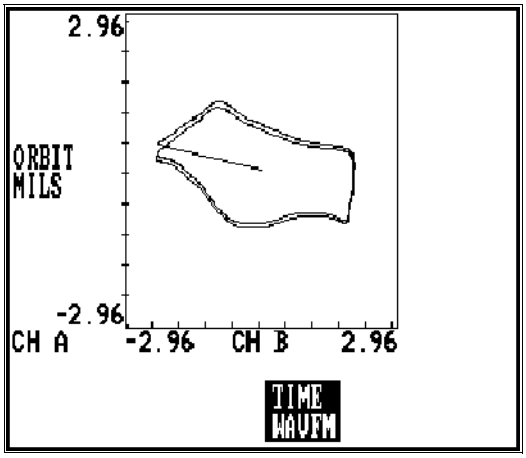
When a tachometer is used, the tach marker lines will be visible in the waveform when the number of waveform points is increased. Remember that 200 Lines of Resolution is equivalent to a sample size of 512. Sample Size and Sweep Size mean the same thing. Tach markers would not be visible with a Sweep Size of 512 because the time waveform time length corresponds to one revolution. If the Sweep Size were doubled to 1024 points, the tach markers would be visible and the waveform length would correspond to the time to complete two revolutions. Two overlapped orbits will be seen in the orbit plot.



The following orbit was measured on a machine with a bent shaft. It was generated from the waveforms shown above.



Orbits, measured using the Analyze/Monitor function of the 2120-2 analyzer cannot be saved.

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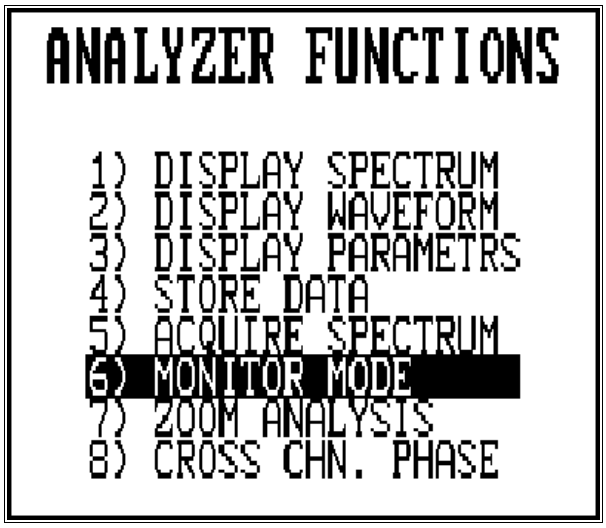
Measuring Orbits in a MT or RBMware Route

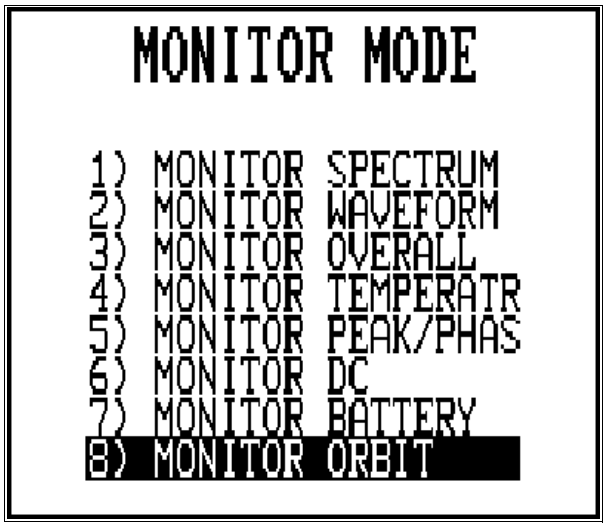
To measure orbits as part of a MasterTrend or RBMware route, measurement points must be collected as dual points. Dual point collection was described in the first part of this chapter.

Measuring Orbits using Analyze/Monitor Orbits

The Monitor Orbit function was implemented in 7.43 firmware. This function offers filtered orbits. Bandpass and Lowpass filtering are available as set-up options. Monitor Orbits is found under Analyze/Monitor Mode.



Monitor Orbit is easy to use and does not require any calculation.



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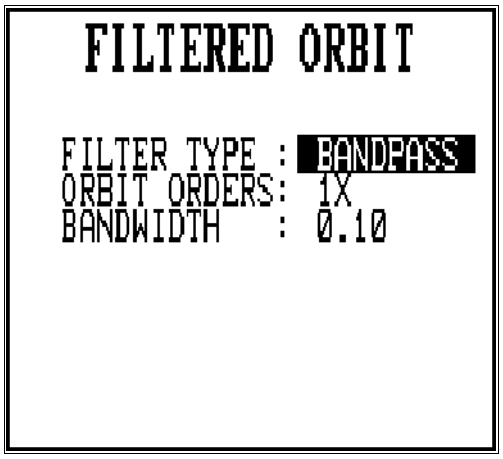
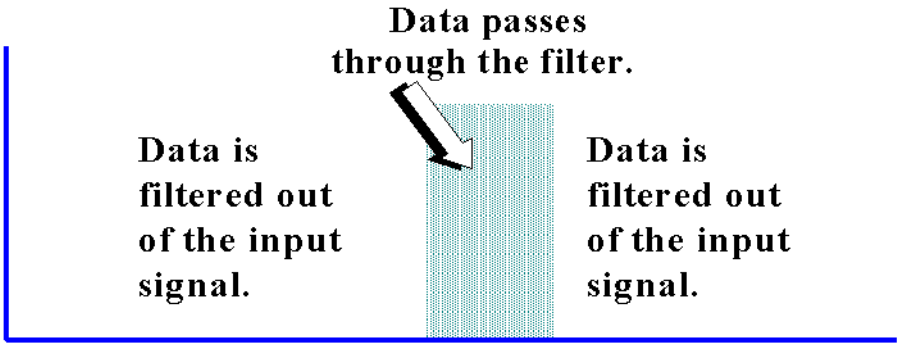
Two filtering options are available: Bandpass and Lowpass. The Bandpass option filters out the signals above and below the bandpass frequency and passes the signal for the order specified. A Bandwidth parameter specifies the width of the band that is passed. The Bandwidth parameter is adjustable between .02 and 1.0 (2-100%) of the order specified. It determines how much of the signal around the order specified passed.

For example: If a 1X order (1800 rpm) is measured, using a bandpass filter of 0.1, the width of the frequency band that is passed is 180 cpm (1800 x .1 = 180).



The shape of a Bandpass filter is shown below. All data above and below the filter is removed from the signal. Only the data within the specified band is allowed to pass. Bandpass filtering requires a tachometer signal.



The other filter option is Lowpass. Lowpass filtering removes all signals above the specified filter setting and passes the signal below the filter value.

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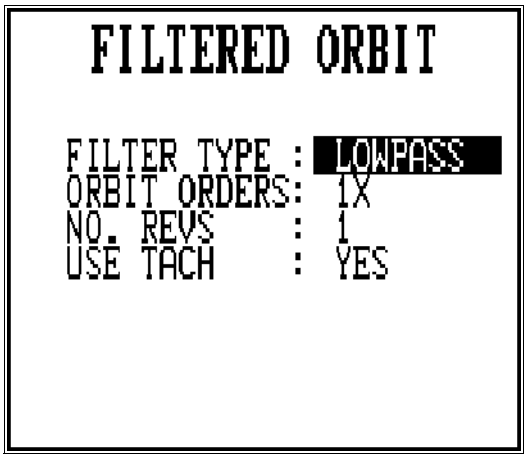
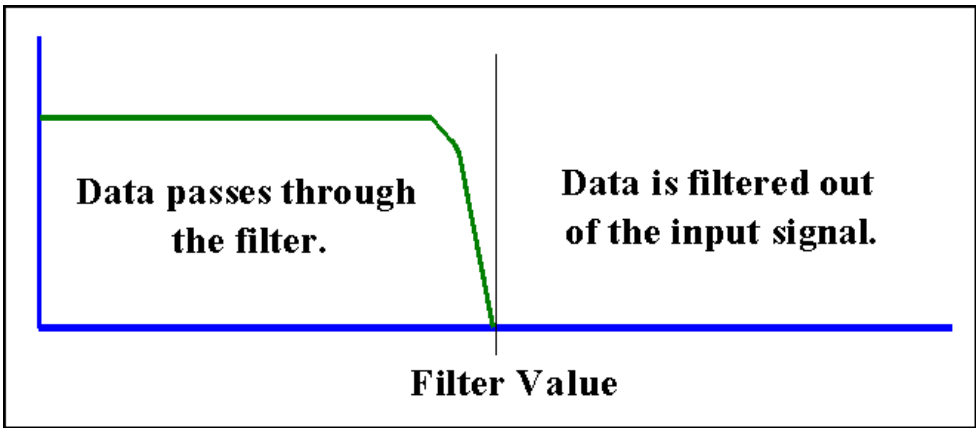
For example: If a 1X order (1800 rpm) is measured, using a lowpass filter, the signal that is passed includes all frequencies at or below the filter value ñ in this example, the orbit includes all frequencies at or below 1800 cpm.



The shape of a lowpass filter is shown below. All data above the specified order are removed from the signal. Only the data at or below the specified order is allowed to pass.



A tachometer signal is optional when using Lowpass filtering. If a tach signal is not available, the orbit frequency is manually entered into the set-up. The exact frequency must be entered

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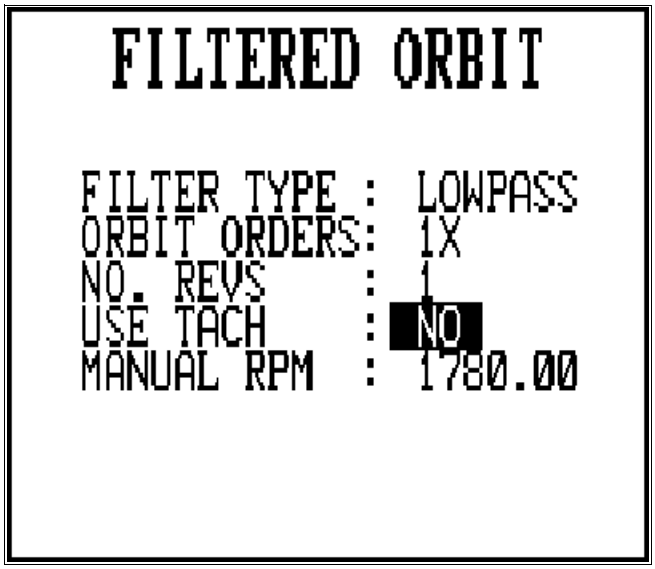

Filtered orbits, measured using the ANALYZE/MONITOR/ORBITS function, can be saved when using LP filtering if a dual measurement point (from a route or OFFROUTE) is currently active on the 2120-2 analyzer.

Note

The save function only works for the Lowpass filter option.

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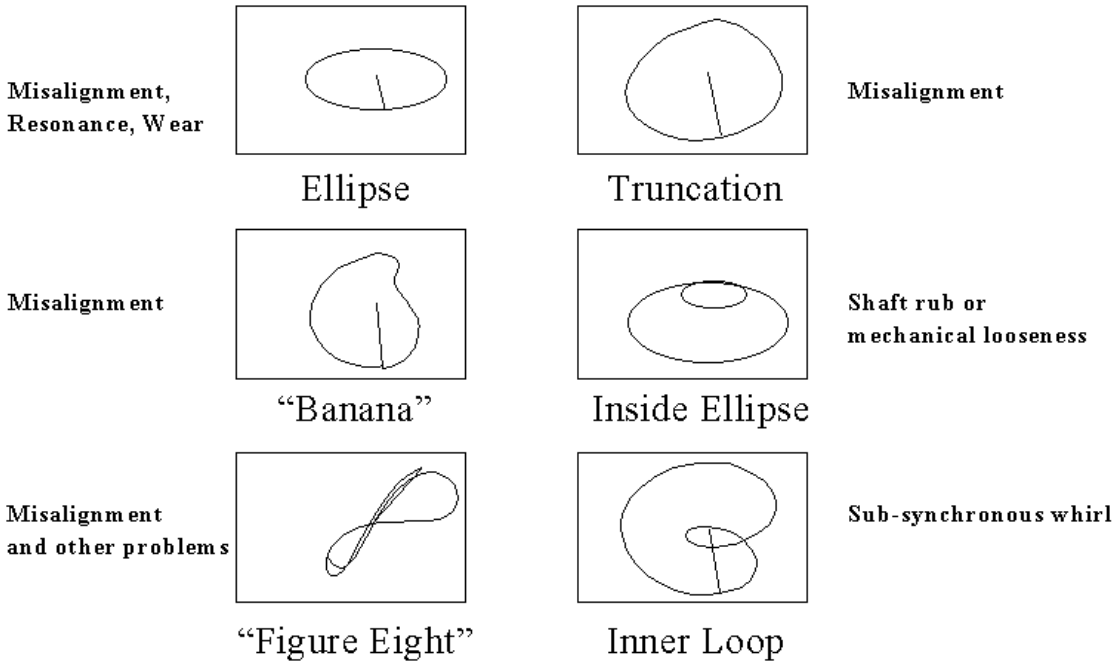
What can an Orbit do for me?

An orbit display provides a visual representation of the shaft centerline rotation. This information may provide a number of different fault characteristics. Orbits are said to be good only when using non-contact eddy current probes (proximity probes). However, this has been proven incorrect. If performed correctly, orbit data may provide some additional insight into the condition of a machine. The illustration below displays different characteristics of typical faults.



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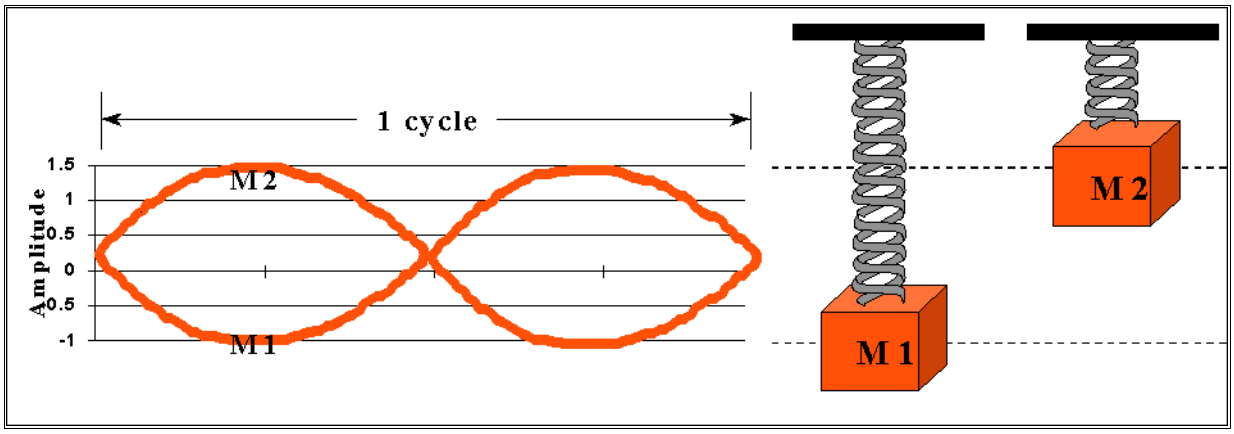
Phase Review

Phase is the position of a part, at any instance, with respect to a fixed point. Phase analysis is one of the most important tools an analyst has to identify specific faults. Too many defects have similar spectral patterns. Phase can help determine the exact problem with a machine.

In the picture below, two machines are vibrating at the exact same frequency but are out of phase with each other by 180 degrees. Inspections of the time waveforms indicate that machine one reaches top dead center when machine two is at bottom dead center.



A single channel analyzer requires a tachometer and reflective tape to trigger the analyzer. Very often, it isn't possible or convenient to stop a machine to install reflective tape. A two-channel analyzer with cross phase capability measures the phase shift between two sensors.

Cross phase measures the relative phase between signals "A" and "B" at each frequency in the spectrum. The cross phase function is a standard feature of the 2120-2 analyzer. Additional capability can be found in the Advanced 2-channel DLP.

In the following examples, the use of phase to analyze faults is explained.

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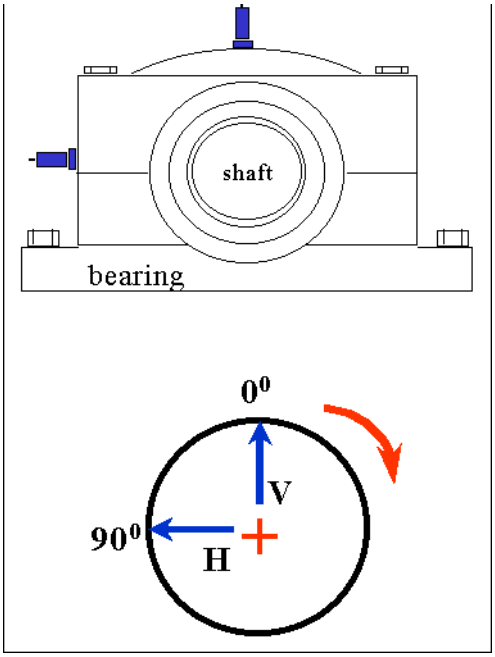
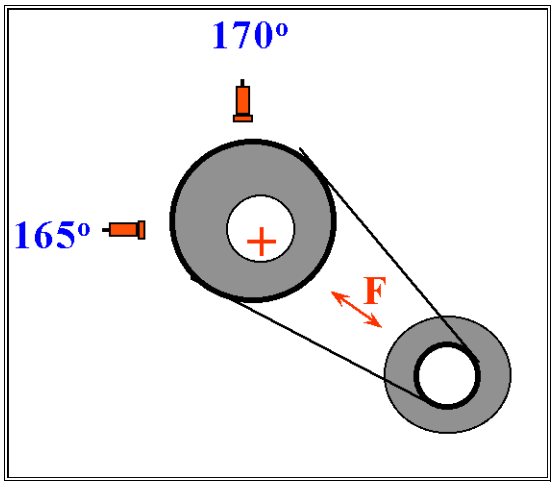
Unbalance

Use Phase to confirm unbalance. Static Unbalance shows a zero degree phase shift across the rotor radial to radial or horizontal to horizontal and a 90-degree phase shift from vertical to horizontal at the same bearing location (within 20 degrees). Dynamic unbalance shows a phase shift across the rotor radial to radial or horizontal to horizontal that is related to the heavy spots on each end of the rotor. If the heavy spots are 180 degrees out of phase on each end, then the phase measurements will also be 180 degrees out of phase.



Reactionary Forces

Use phase to find problems that look like unbalance but are really caused by something else. In the following example, the predominant frequency is turning speed of the large pulley. Comparative horizontal to vertical phase readings indicates a zero or 180-degree phase shift from horizontal to vertical. It looks like unbalance but it's really an eccentric sheave -- a well balanced, eccentric sheave. An orbit of this data would indicate an elliptical shape in line with the drive belt.



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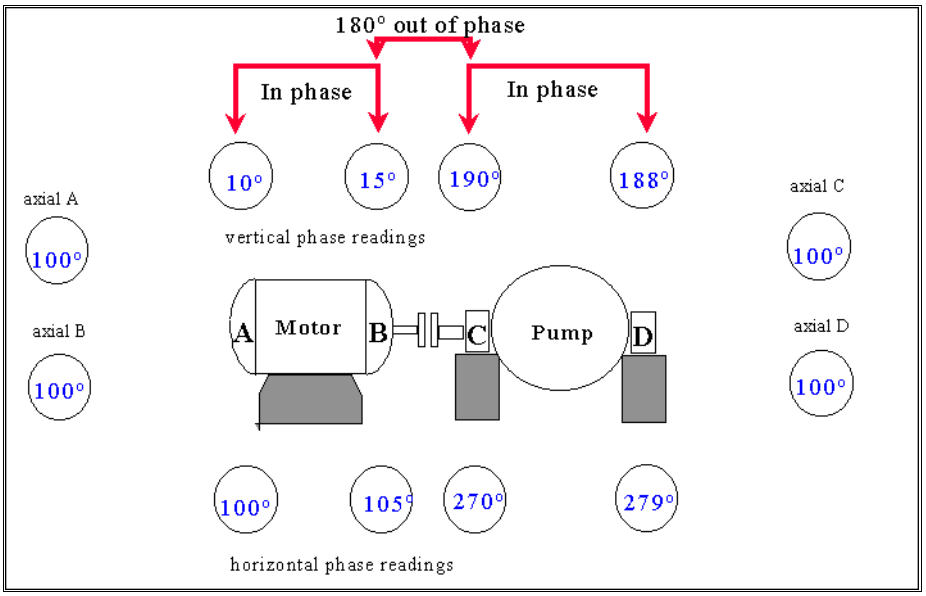
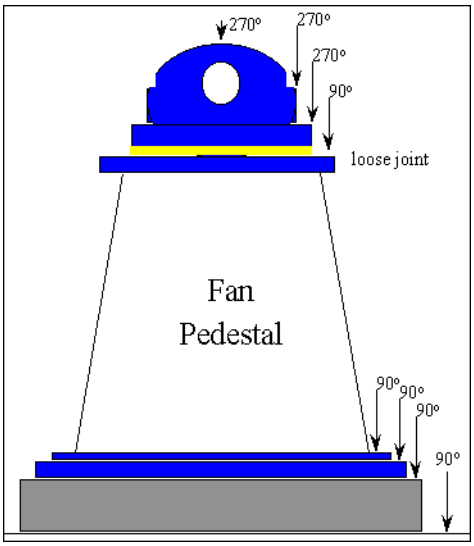
Misalignment

Angular misalignment will typically show a 180-degree phase shift across the coupling in the axial direction. Parallel misalignment will tend to show a 180-degree phase shift across the coupling in a radial direction (within 30 degrees). Phase measurements, made on all bearings in the horizontal, vertical and axial directions will confirm the misalignment type.



Looseness and Soft Foot

Phase reading with looseness will be erratic from point to point around the machine train. A soft or loose component usually shows a phase shift between the tight and loose joints. Often this shift will be greater than 90E and as much as 180-degree. To identify the source of looseness on a machine, measure phase across all bolted or welded joints. When the phase shifts, the looseness has been found. For soft foot, measure phase across the bolted joint and compare to the other machine feet.



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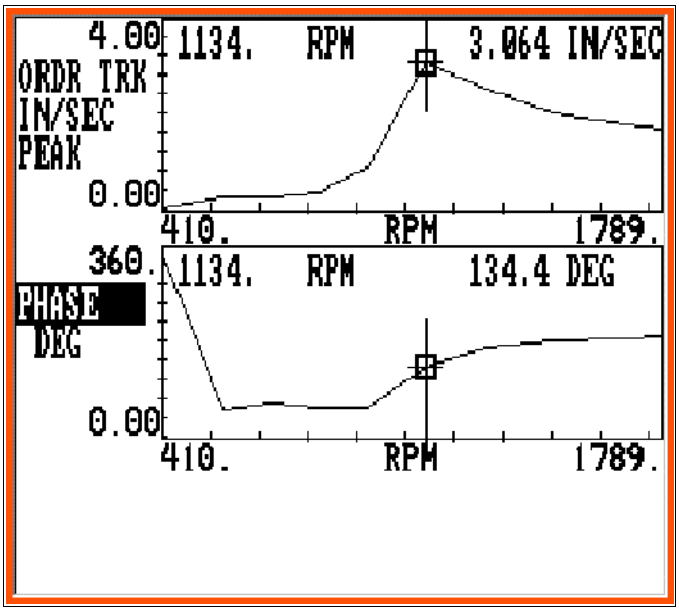
Resonance

Through resonance, phase shifts 180 degrees. At resonance, a 90-degree phase shift will be present. A Bode plot of coast-down data is an excellent test to verify resonance. As the amplitude peaks, the phase shifts 180 degrees.



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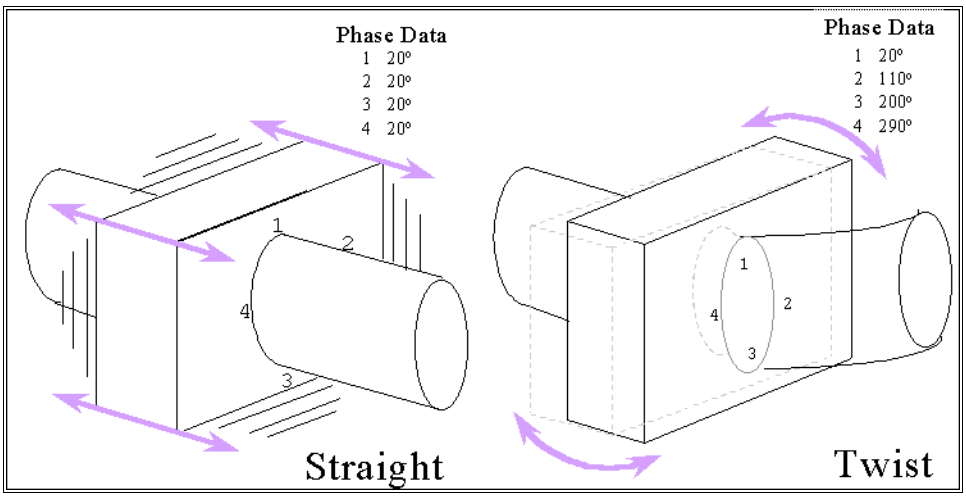
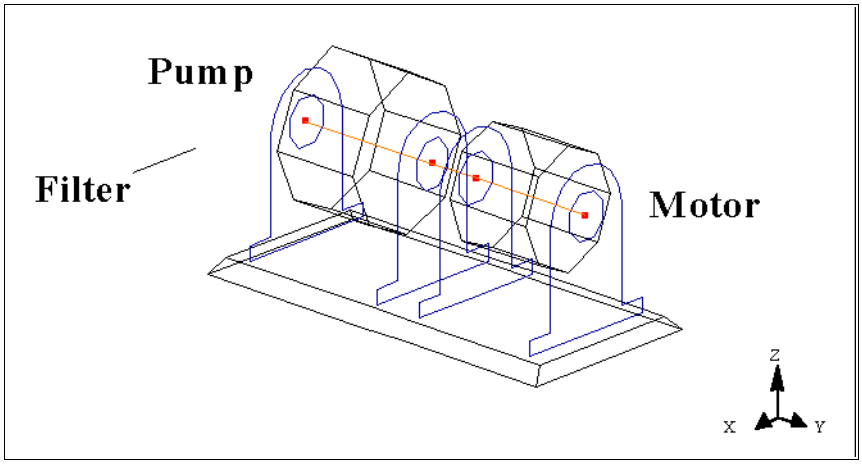
Bent Shafts / Bearing Twist

Phase can easily identify a shaft bent through its bearing or a self aligning bearing where the outer race and housing are not perpendicular with the shaft. To test for this condition, take phase measurements around the face of the bearing. If the phase is steady (within 30 degrees) the bearing is not twisting. If the phase is constantly changing at each position measured, it is an indication of twist in the bearing or bend in the shaft through the bearing.



Operational Deflection Shapes

Operational deflection shapes (ODS) use phase and magnitude data to animate the motions of machines and structures during normal operation.



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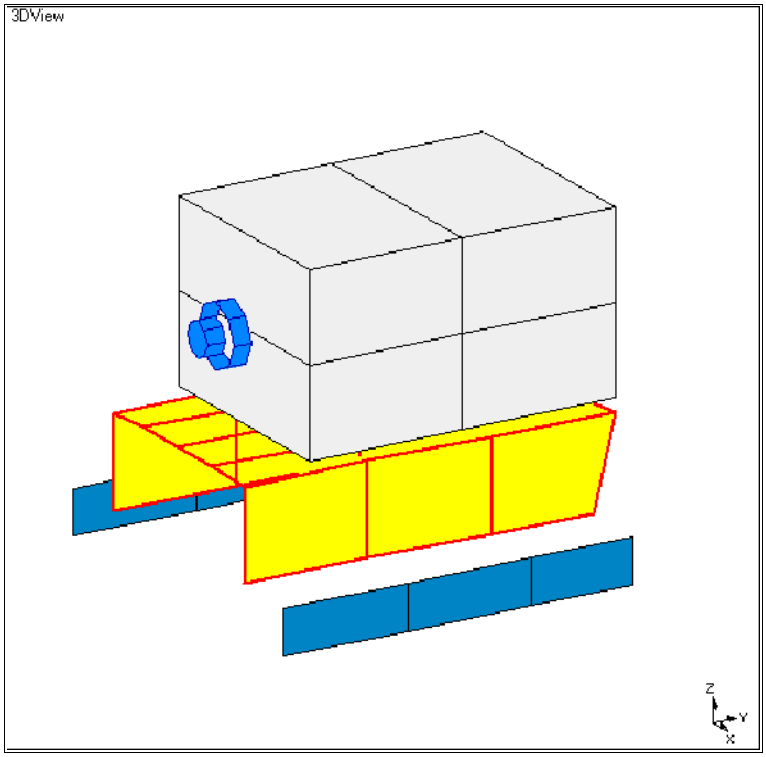
Modal Analysis

The transfer function response to a known input force is used to animate the shapes of machines and structures at the natural frequencies.



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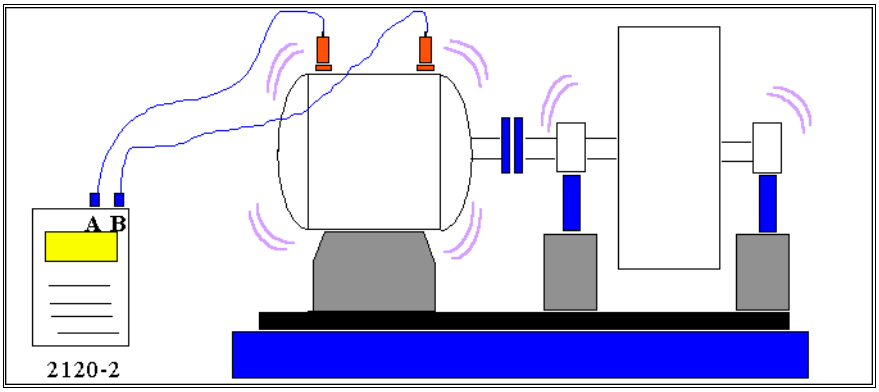
Cross Channel Phase Measurements

Expanding on the definition previously stated, cross channel phase measurements only simplify and expedite phase data acquisition. Of all cross channel measurements, cross channel phase is the most sensitive vibration parameter.

The following are some basic considerations that must be taken into account when acquiring multichannel phase data:

- An accelerometer is the only ***true phase*** transducer.
- The multichannel FFT analyzers have no internal phase shift between channels.
- Phase is measured using two sensors
- Phase is obtained at any frequency within the specified F_{max}
- The machine does not have to be stopped to apply reflective tape for a tachometer

Cross-phase is a by-product of the cross spectrum. The process for measuring cross phase is to leave one sensor at a fixed position while moving the second sensor to all other measurement positions. The position and direction of the fixed sensor do not matter. All measured positions will have a phase that is relative to the fixed sensor. In the example below, the phase at each bearing and direction is measured when channel "A" is the fixed sensor and channel "B" is roved to other positions and directions. Aside from bearing measurements, the motor feet, motor base, pedestals, sole plate, concrete base and floor can also be measured.



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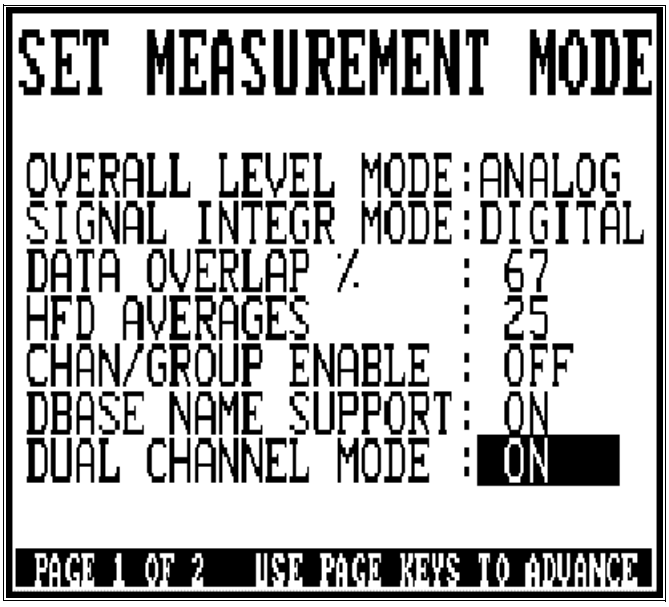
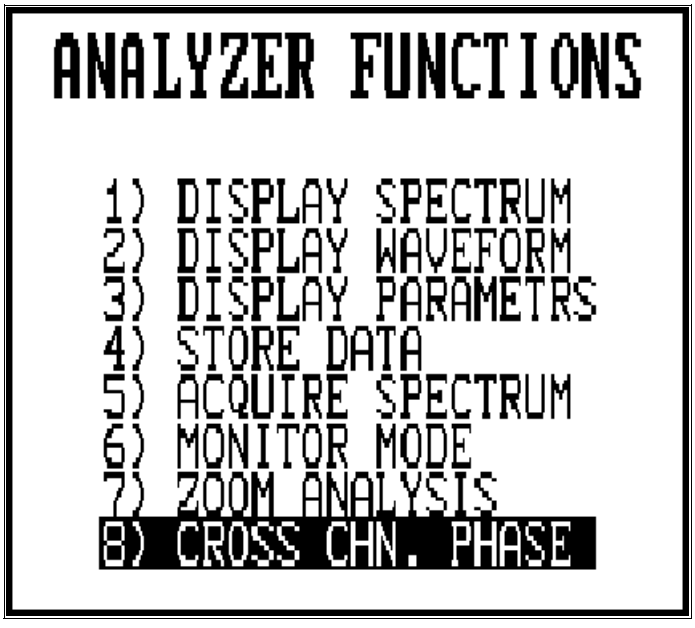
As mentioned above, cross phase is a standard feature of the 2120 analyzer. It is, however, only an option in the Analyze menu if the analyzer has been enabled for dual channel measurements. To verify that the analyzer is enabled, press Utility, Change Set-up, Measurement Mode and verify that Dual Channel Mode is turned to **ON**.


SET MEASUREMENT MODE
OVERALL LEVEL MODE:ANALOG
SIGNAL INTEGR MODE:DIGITAL
DATA OVERLAP %: 67
HFD AVERAGES: 25
CHAN/GROUP ENABLE: OFF
DBASE NAME SUPPORT: ON
DUAL CHANNEL MODE: ON
PAGE 1 OF 2 USE PAGE KEYS TO ADVANCE

The Cross Phase function is located in the Analyze menu.



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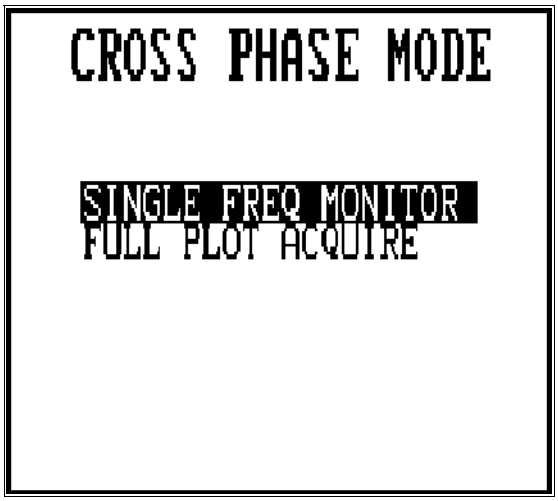
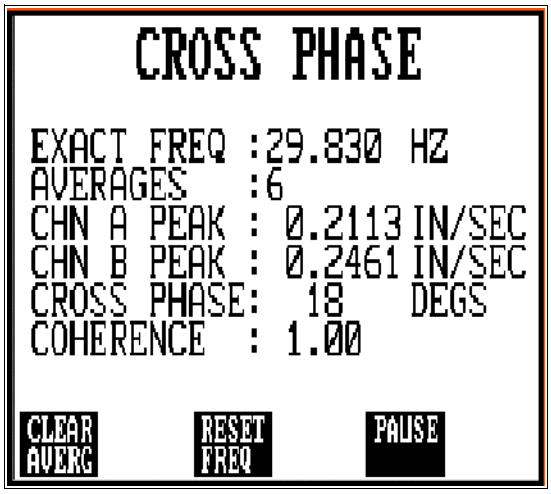
Cross phase measures at a single frequency or over a full spectrum.



The single frequency monitor option requires the analyst to enter the frequency span, frequency of interest and lines of resolution. The resulting measurement screen shows the magnitudes of channels "A" and "B" and the cross phase between the two channels. The coherence between the two channels is also displayed. Coherence is discussed in the next section of this chapter.

The full plot acquire mode has a few more set-up fields than the single frequency monitor mode and returns a full spectrum of cross phase. The plot definitions can be changed by pressing the F1 key. To analyze phase, it is recommended to make one plot the averaged spectrum of the roving sensor and the other plot the cross phase. Use the **page** keys to shift cursor control between plots. Find the frequency of interest in the averaged spectrum plot then read the phase shift, at that frequency, in the cross phase plot.



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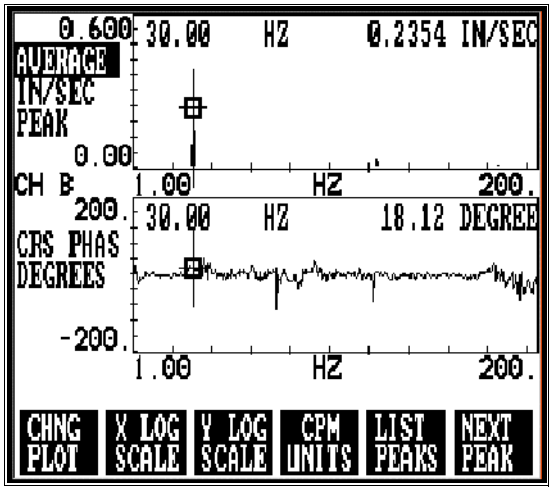
In the phase trace shown below, the phase is essentially flat, at zero, across the spectrum - indicating no phase shift between the two sensors at any frequency.



Regardless of the mode used to acquire phase and magnitude data, the information must be manually recorded. Cross phase, as a standard feature of the 2120-2 analyzer, has no provision for storing data.

There are two methods of manually recording phase and magnitude data. The first method is a simple table of data like the one shown below. Each frequency evaluated will have a similar table of data.

Point	Mag	Phase
MOH		
MOV		
MOA		
MIH		
MIV		
MIA		

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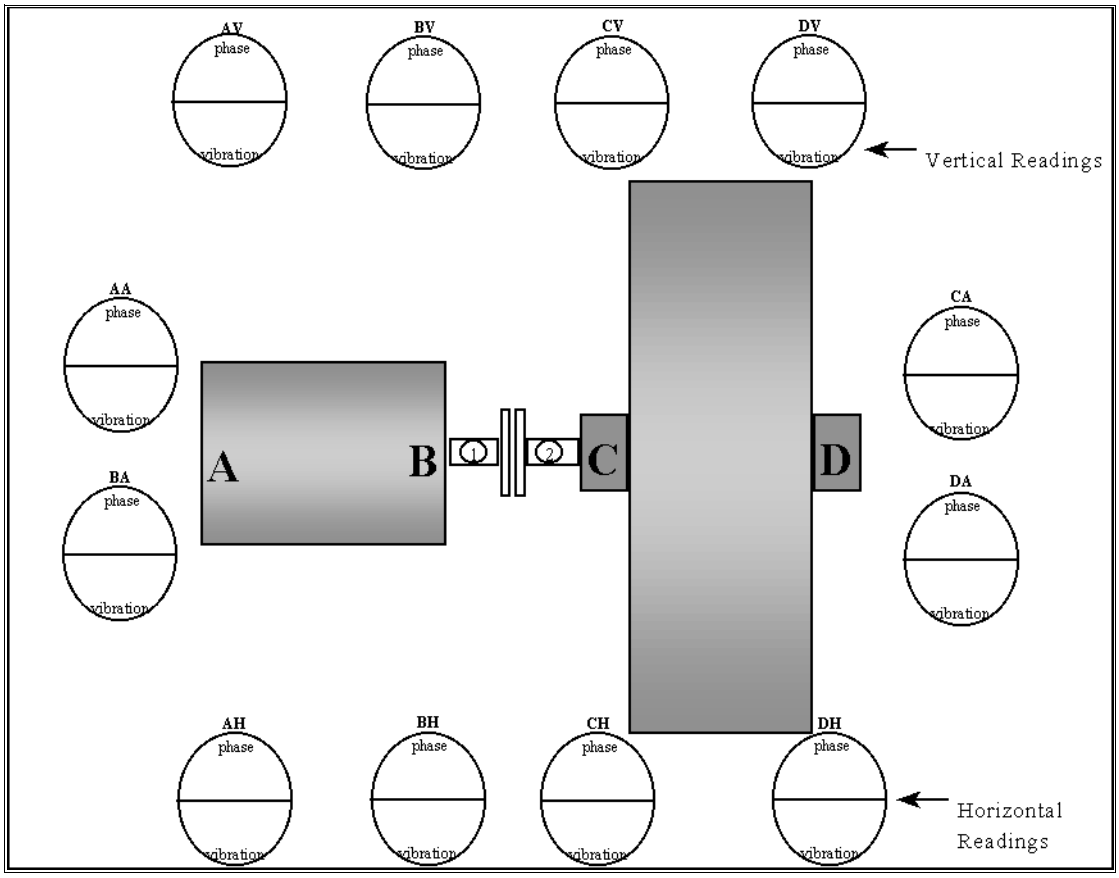
The second method uses a bubble diagram of the machine to record the measured values.



Once the data has been acquired, it must be analyzed. Depending on the machine fault present, machine components will either be moving in phase, or out of phase. Obviously, when many positions and directions have been measured, the analysis becomes more complicated without the help of an ODS display program. The phase and magnitude readings can be manually entered into an ODS display program like ME'scope where a drawing of the machine is animated.

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The optional, Advanced 2-channel DLP, simplifies collection of cross channel data. The three primary advantages of using the DLP for phase measurements are:

1. Measurements may be stored to analyzer memory and downloaded to VibPro software.
2. Stored data is analyzed in VibPro software
3. Stored data is transferred to ME'scope ODS program

Review of Cross Channel Phase

Cross-channel phase is measured as a standard feature of the 2120-2 analyzer. Cross phase measurements do not require a tachometer and are made without interrupting machine operation. Analysis of phase data is simplified with ME'scope ODS software and the optional Advanced 2-channel DLP for the 2120 analyzer.

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Cross Channel Phase Lab

Follow the instructor's directions and measure cross phase on a demonstration machine in the lab. The 2120-2 analyzer will be used with standard firmware.

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Cross Channel Coherence

Coherence or *coherency* measures the degree of linear relationship between two signals. It has a similar role in frequency analysis to the correlation coefficient in statistical analysis.

Coherence is a by-product of the measurement of the cross channel properties of two signals in multichannel spectrum analyzers, which makes them self-checking.

Coherence is available on the 2120-2 analyzer under the Cross Phase option of the **Analyze** mode.

Coherence measures the degree of linear relationship between two signals and reports back a value between 0 and 1. A value of zero indicates that the two signals are unrelated. A value of 1 indicates that the two signals are completely related. Coherence has many uses. One of the more typical uses of coherence is as a quality check on impact tests and modal analysis.

Calculating Coherence

Coherence is calculated from the cross spectrum between signals A and B and the power spectrums of each of the two signals. Coherence is represented by the symbol $\gamma 2$. The formula for coherence is shown below.

$$\gamma^2 = \frac{[Mag.\ Cross\ Spectrum\ A\ B]}{[Pwr\ Spectrum\ A] \times [Pwr\ Spectrum\ B]}^2$$

Notice that the numerator is the magnitude of the cross spectrum squared, and the denominator is the spectrum of channel A times the spectrum of channel B. When these values are divided into one another, the result is a ratio that varies from 0 to 1.

An acceptable value for coherence is above 0.9 or 90%. In high noise environments, an acceptable value could be 0.7 or higher.

Coherence = 1.0 means the signals are related

Coherence = 0.0 means the signals are not related

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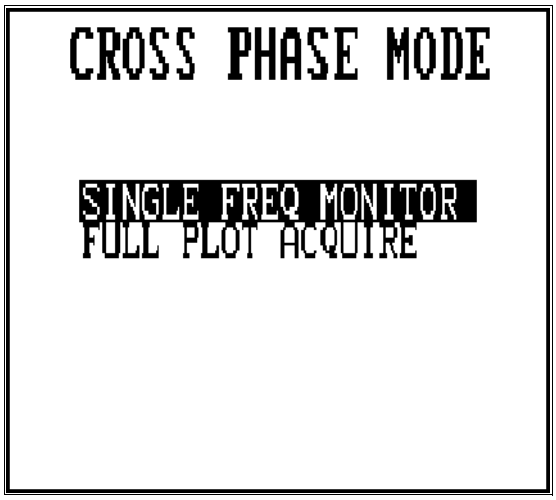
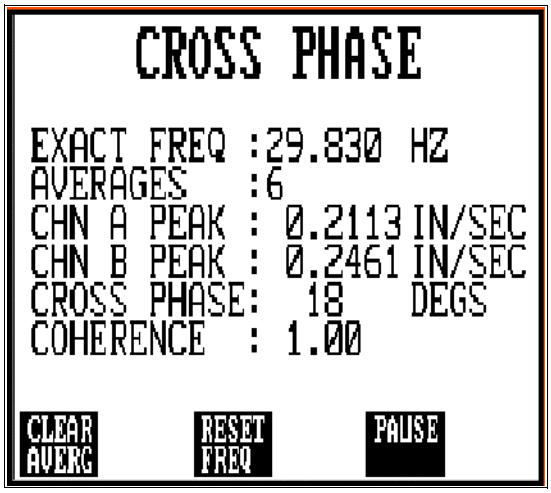
Spectral data is evaluated for coherence on a frequency by frequency basis ñ just like cross phase. Coherence is an averaged function and, as the number of averages increases, the value of the coherence decreases.

For the first average, all data across the spectrum are coherent, therefore more than one average is required. As a rule, use 4-10 averages for coherence data.

Coherence is measured in the Analyze/Cross phase function of the 2120-2 analyzer. The **Single Frequency Monitor** and **Full Plot Acquire** screens were discussed earlier in this chapter.



In single frequency monitor, coherence at the frequency of interest is displayed along with cross phase and the magnitudes of channel A and B. Averaging is continuous in this mode, so be careful not to over average the coherence data.



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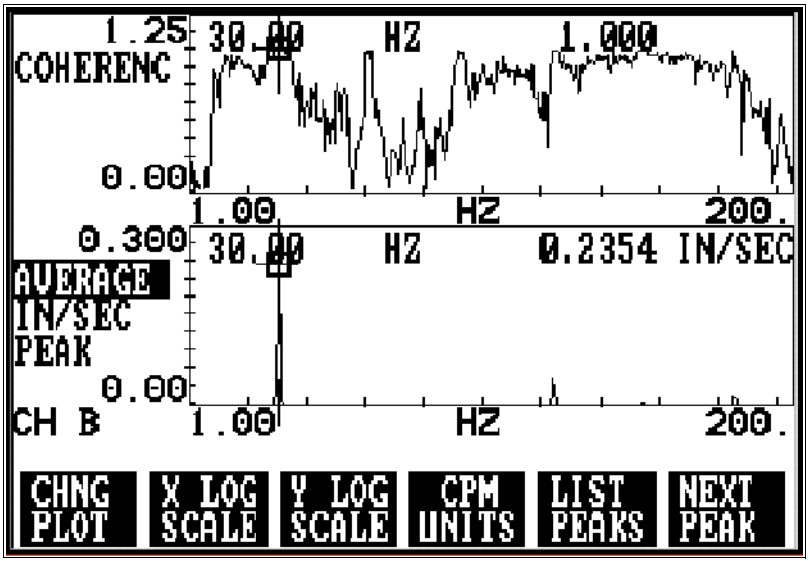
In Full Plot Acquire, the signals are averaged to the specified number of averages. When the resulting plots are displayed, cross phase and coherence are shown. The plot definitions can be changed by pressing the F1 key. To analyze coherence, it is recommended to make one plot the averaged spectrum of the roving sensor and the other plot the coherence. Use the **page** keys to shift cursor control between plots. Find the frequency of interest in the averaged spectrum plot then read the coherence, at that frequency, in the coherence plot.



In the data shown above, the coherence at the vibration peak (30 Hertz) is measured to be 1.0 -- indicating that the vibration on the two sensors is related at that frequency. Coherence is evaluated at each relevant frequency (*i.e., where there is vibration energy*). Coherence values will be low where vibrations are extremely low.

Causes of Low Coherence

Low coherence can result from many different factors. Two examples of poor coherence are shown below.

1. Transmissibility Measurement:

Consider two accelerometers placed on a machine. Assume that the only vibrations are at synchronous speeds and the spectrum was measured to 200 Hertz. A coherence trace will show the following:

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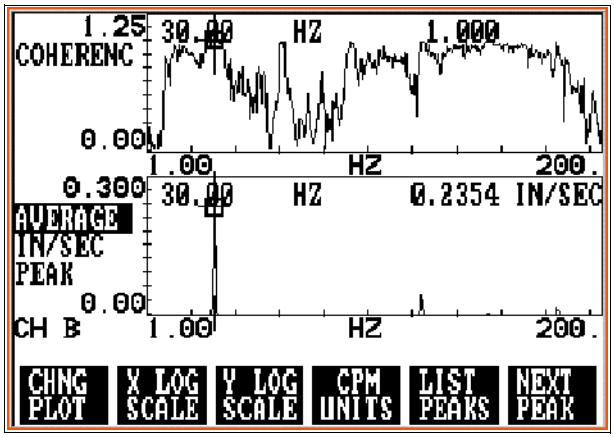
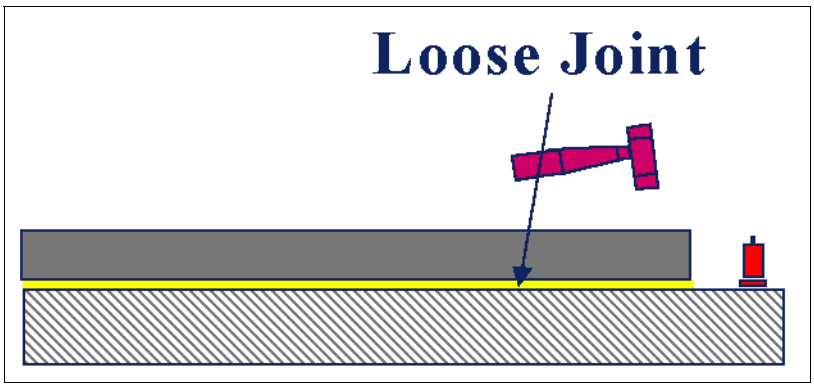
- A coherence of 1.0 at the first few orders where vibrations are noticeable.
- A coherence of 1.0 at higher order harmonics (*even though the amplitudes are very low the coherence will be high*).
- Poor coherence at non-synchronous frequencies because there is no vibration source common to both accelerometers.



2. An example of low coherence over the entire frequency range:

In this example, the coherence between a force hammer and accelerometer is measured during impact testing. The two surfaces being tested are bolted together. Both the hammer and the accelerometer are connected to the 2120-2 analyzer. Four averages were made for each test.



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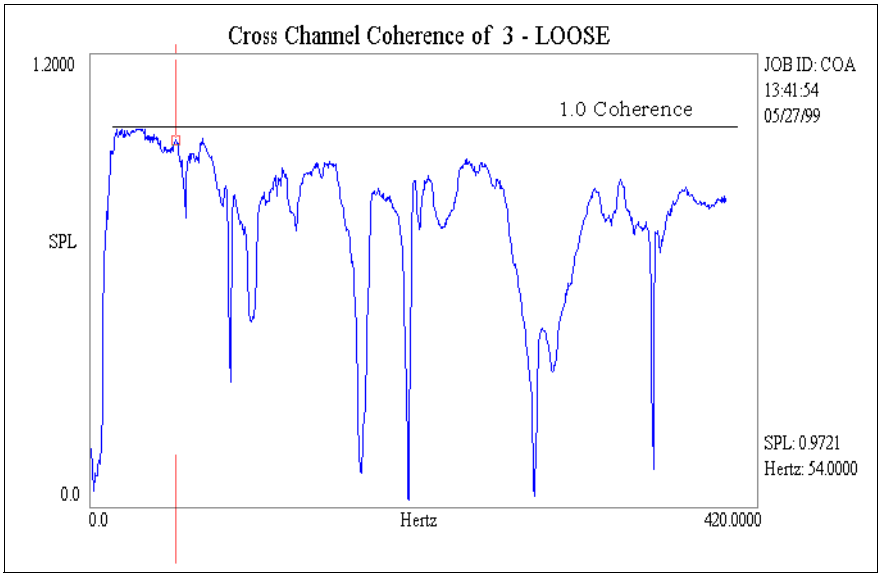
The data shows very low coherence across the frequency range. A flat line at 1.0 was expected. The hammer hit puts low level energy into the structure over a broad frequency span. The extent of the frequency span depends on the hammer tip hardness. If the hammer tip were able to deliver energy through the sole plate to the concrete, the accelerometer would have measured the energy and the coherence plot would be a flat line at 1.0. It wasn't. The coherence drooped below 1.0 over most of the frequency range.



It was discovered that the bolted joint was loose. The looseness resulted in poor coherence.

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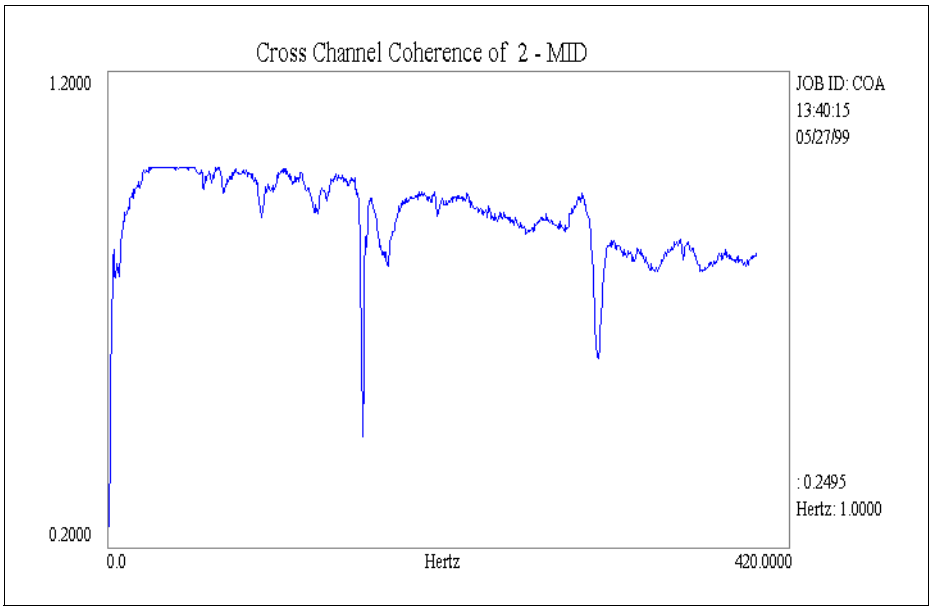
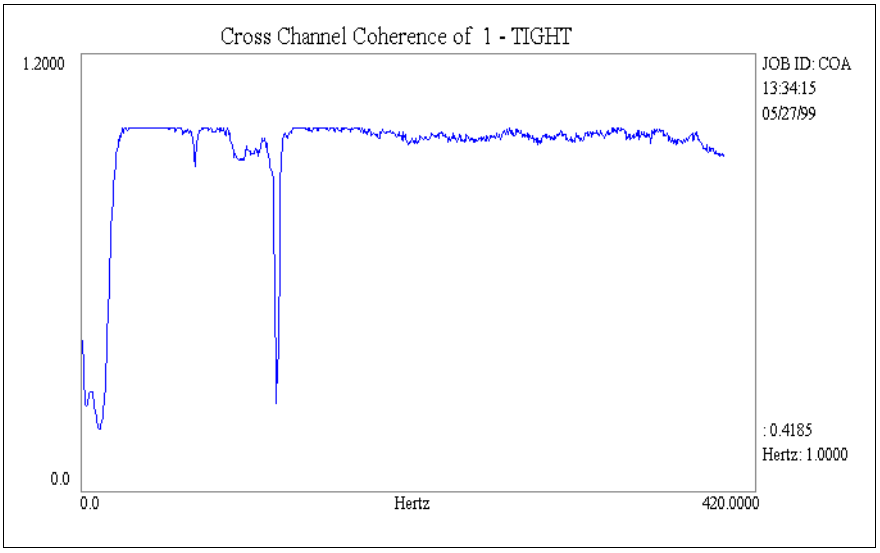
To see the relationship between looseness and coherence, the plate bolts were tightened a little at a time. The following coherence trace was made after the bolts were hand tightened. The trace has fewer dips and higher coherence.



After the bolts were tightened, the following coherence measurement was made. Notice how the trace is flat over the frequency span.



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Low coherence results from a variety of different conditions. Some are listed below.

- Low signal level
- Structural nodal points
- Background vibration
- Non-linearity
- Double hits during impact testing
- Defective cable or sensor
- Poor sensor mounting

Coherence can be an extremely useful function in vibration analysis. Coherence indicates the relationship between two signals.

If signal 1 and 2 are coherent, one or more of the following are true statements.

- The system is linear
- "A" caused "B"
- "B" caused "A"
- "A" and "B" are caused by something else

If two signals are coherent, don't assume that the one with the higher amplitude caused the one with the lower amplitude. It may not be true.

The optional, Advanced 2-channel DLP, simplifies collection of cross channel data. Measurements can be stored to the 2120-2 analyzer and transferred to VibPro software for analysis.

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Coherence Lab

Follow the instructor's directions and measure coherence on a demonstration machine in the lab. The 2120-2 analyzer will be used with standard firmware.

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Triggered Data Capture

Section 9

Objectives

- Define triggered data.
- Apply triggered data capture to solve vibration problems.

CSi means Reliability Training

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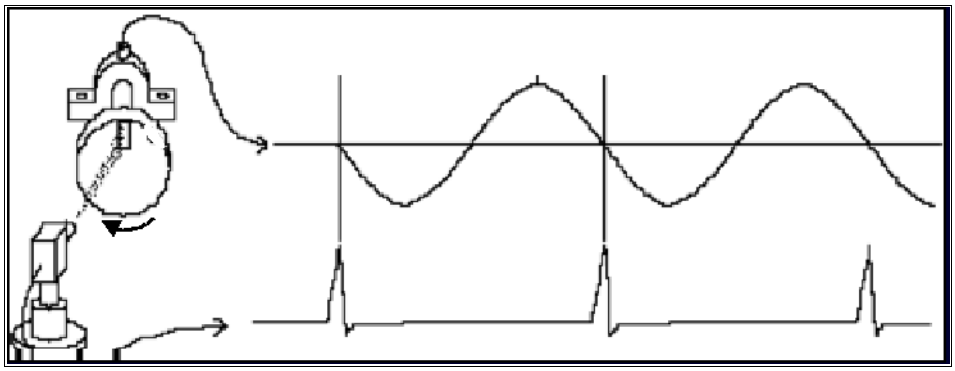
Introduction

A trigger is an event used to initiate the measurement. In the absence of a trigger signal, the analyzer will make measurements at its own pace based on the F_{max}, lines of resolution and overlap settings. Triggering can be used for both periodic and nonperiodic signals. Triggered data collection is extremely useful when the vibration signal is non-periodic.

Triggers can be internal or external to the analyzer. Triggering occurs when a trigger pulse (from a tachometer) or a vibration signal amplitude exceeds the trigger set point.

The picture below shows a once per revolution tachometer pulse used to trigger the analyzer.



Many different signal types can be used as a trigger. A trigger can come from a sensor signal or impact hammer connected to one of the data channels. The trigger signal can be from a tachometer or stroboscope signal connected to the tachometer port. The analyzer's internal clock is also a trigger (internal trigger) that initiates another measurement to begin once the previous measurement has been completed.

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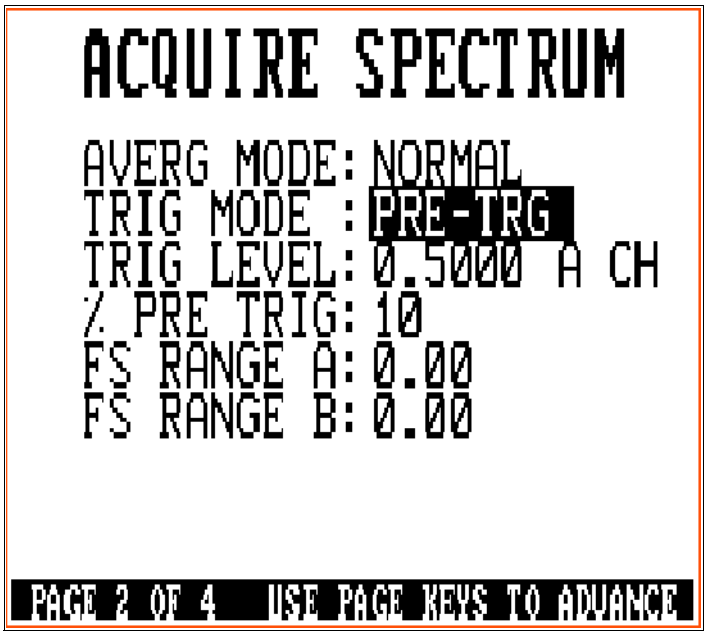
Trigger Settings Explained

To enable triggering from the Analyze | Acquire Spectrum, Analyze | Monitor Waveform or Analyze | Monitor Spectrum functions, page down to the averaging and triggering set-up screen. Cursor down to the TRIGGER MODE field. Press any alphanumeric key to toggle through the four available trigger modes.


ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : PRE-TRG
TRIG LEVEL: 0.5000 A CH
% PRE TRIG: 10
FS RANGE A: 0.00
FS RANGE B: 0.00
PAGE 2 OF 4 USE PAGE KEYS TO ADVANCE

Average Mode

The Averaging function has nothing to do with the triggering options.

Trigger Mode

Four trigger modes, plus OFF are available. Note that two of the four trigger modes deal with TACHS (inputs to the tach port of the analyzer) and two deal with data channels. The trigger modes are:

OFF

No triggering. This mode causes the analyzer to measure based on its own internal clock. The measurement interval is determined by the Fmax, lines of resolution and overlap settings. If the trigger mode is set to off, the Trigger Level and Percent Pre-trigger settings do not matter.

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TACH

The Tach mode causes the analyzer to trigger from a tachometer signal connected to the Tachometer Port (BNC).

Pre-TACH

This mode is the same as TACH but shows an adjustable amount of pre-trigger signal in the waveform display. Pre tach requires a signal connected to the Tachometer BNC connector on the analyzer.

Normal

The Normal trigger mode results in a trigger based on one of the two signal input channels (**A** or **B**). When Normal triggering is used, a trigger level must be specified.

PRE-TRIG

This mode is the same as Normal but shows an adjustable amount of pre-trigger signal in the waveform display.

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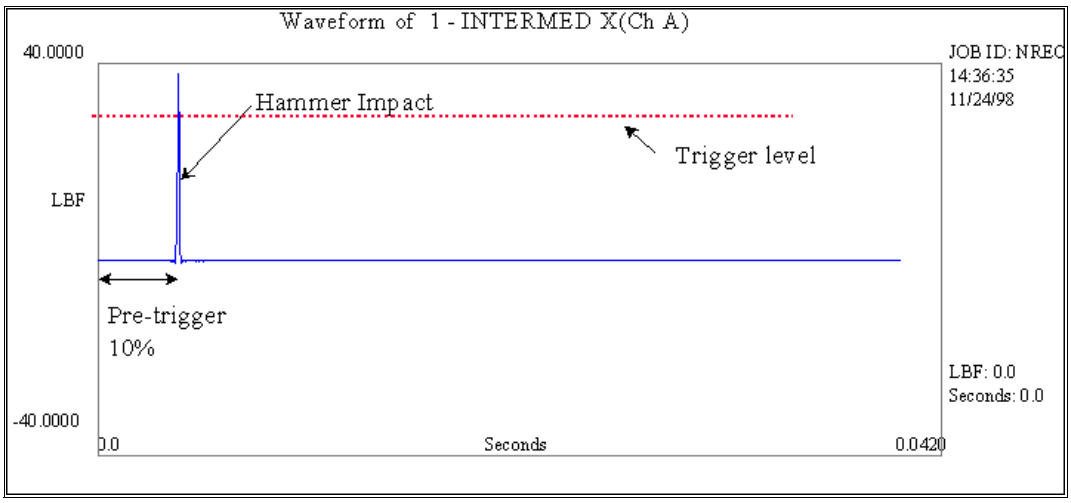
Trigger Level

The trigger level is used to specify a trigger signal level from one of the two data input channels (**A** or **B**) when Normal or Pre-Trigger is selected as the trigger mode. The value of the trigger level is in waveform units. When the measurement is started, the analyzer is armed and waiting for trigger until the signal level reaches or exceeds the trigger level. The picture below illustrates a measurement triggered from an impact hammer connected to channel "A". The impact exceeded the trigger level set at 30 pounds and caused the analyzer to acquire data.



% Pre-Trigger

When **Pre-Trig** or **Pre-Tach** is selected as the Trigger Mode, the % Pre-Trigger field specifies how much time, before the trigger, will be seen in the time waveform. The pre-trigger value is a percentage of the total time waveform time interval. The picture above shows the hammer impact offset from the left edge of the time waveform. This offset is equal to the pre-trigger amount. A 10% pre-trigger means that 10% of the total waveform length is seen prior to the trigger event.

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The purpose of the Pre-Trigger is to offset the trigger from the left edge of the waveform. If the hammer impact was at the left edge of the time waveform, it would be very difficult to evaluate the impact. Pre-trigger values can be set to any percentage. Ten percent is typically used. The Pre-trigger has no effect on the spectrum when the Uniform Window function is used. When the Hanning Window Function is used, the effect of Pre-trigger on the spectrum depends on the type of signal (periodic vs. transient) and if transient, how much pre-trigger is used.

Trigger Channel

This field specifies the data channel to trigger from when Normal or Pre-Trig are selected as the trigger mode. Both channels can be used for measurement of the triggered signal, however only one channel can trigger the measurement.

- If Dual Channel Mode is not on, the trigger channel field will not be visible and the trigger channel will be channel "A" by default. *Dual channel mode is turned on through the Utility | Measurement Mode screens*.
- If **BOTH** channels are not selected for display in the measurement set-up, the trigger channel field will not be visible and the trigger channel will be channel "A" or "B" depending on the *display channels* setting. *Display channels "A", "B" or "Both" is selected on the next page of the measurement set-up in Analyze | Monitor or Acquire*.
- Only when Dual Channel Mode is set to "***ON***" and "***BOTH***" channels are selected for display will the Trigger Channel field be visible

To highlight the Trigger Channel field, arrow down past the F.S. Range fields until the highlighted cursor is on the Trigger Channel field. Press any alpha-numeric key to toggle between channel "A" or "B".

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F.S. Range

The F.S. Range fields control the signal input buffer range setting. The F.S. range setting tells the analyzer how much incoming signal to expect on each channel.

When the F.S. Range fields are set to Zero, the analyzer auto-ranges when the Enter button is pressed to start the measurement. The input buffer is set to accept signal slightly larger than the current incoming signal. If the signal level changes during the measurement, the analyzer may pause and change range or indicate "Signal Overload" on the display.

When the F.S. Range fields are set to some number other than zero, the analyzer's input buffer is fixed to accept incoming signal to that value before overloading.

The value for the F.S. Range is in waveform units. When in dual-channel mode, both F.S. Range fields must be either zero or non-zero number.

Set the F.S. Range to zero for periodic data and impact testing. When impact testing, the analyzer will require a few practice hits to set the proper range.

When triggering on vibration or some other data signal, set the F.S. Range field to a level that is just above the current signal level for each channel.

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Measurements that use Triggering

Many vibration analysis measurement techniques use triggering. Some of these techniques are listed below. The Trigger Mode used for each technique is in parentheses.

Bode Plots

Used for coastdown studies (TACH)

Single Channel Phase

Used for phase analysis, balancing and operational deflection shape studies (TACH)

Synchronous Averaging

Used to average out all data that is non-synchronous to a tachometer signal (TACH)

Order Tracking

Used when measuring variable speed machines (TACH)

Impact Testing

Used for finding natural frequencies (Pre-Trig)

Time Studies

Used to analyze gearbox data (Normal)

Transient Events

Used to start the analyzer precisely when the event occurs

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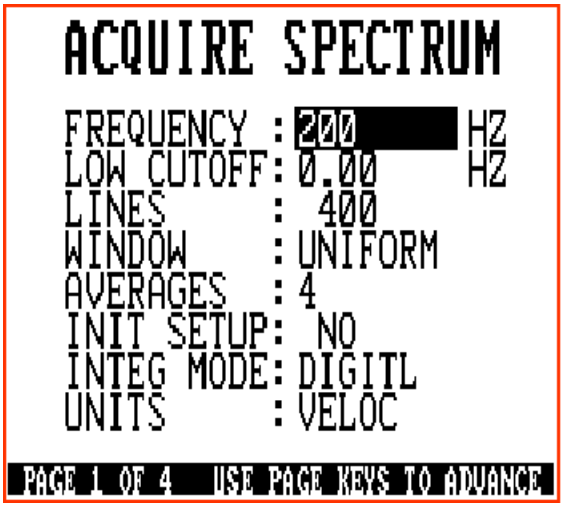
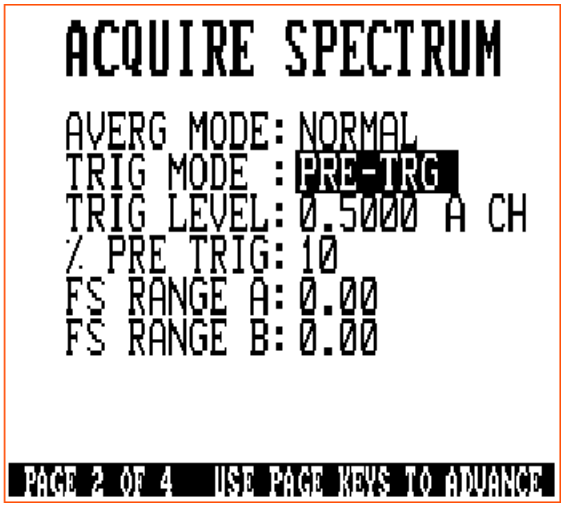
Single Channel Impact Trigger

Let's examine the steps required for a single channel bump test using pre-trigger. From the ANALYZER FUNCTIONS menu, choose, **ACQUIRE SPECTRUM** and press **Enter**.

Set-up the measurement for 200 Hertz, 400 lines of resolution with UNIFORM window function. Uniform windowing is equivalent to using no window function and does not change the data in any way. HANNING window function is used for periodic data and would not be a good choice for a triggered impact test.

Page down to the trigger set-up page and cursor down to the TRIGGER MODE field. Choose PRE-TRIG as the trigger mode.




ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : PRE-TRG
TRIG LEVEL: 0.5000 A CH
% PRE TRIG: 10
FS RANGE A: 0.00
FS RANGE B: 0.00
PAGE 2 OF 4 USE PAGE KEYS TO ADVANCE

A trigger level of 0.5 on channel "A" means that the analyzer will trigger and take a measurement when the channel "A" signal level exceeds 0.5. The units for this number will be whatever the waveform units indicate. In this case, using Digital Integration, the waveform units will be G's.

A pre-trigger of 10% places the start of the triggered measurement 10% to the right of the time window start point. The advantage for using pre-trigger is that, in the case of an impact, it is much easier to see the impact if it is away from the left edge of the time window. The percent pre-trigger value does not affect the spectrum.

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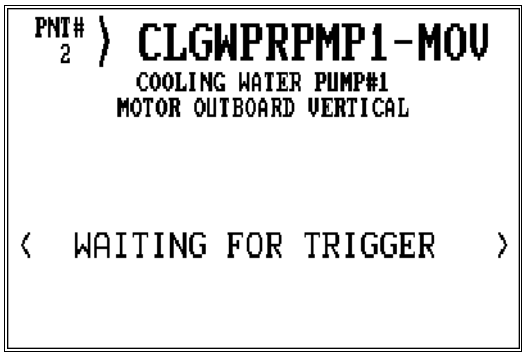
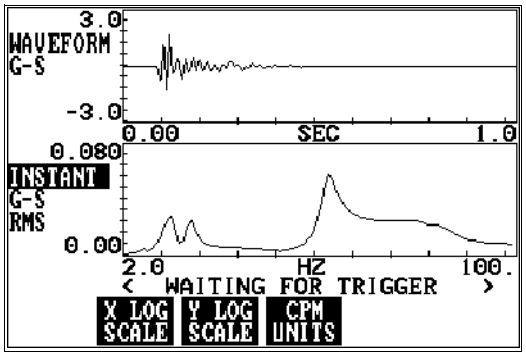
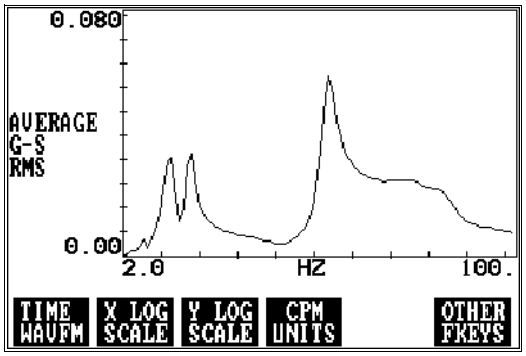
Press **Enter** to start the measurement. After the analyzer auto-ranges, press Enter again as instructed. The message < **WAITING FOR TRIGGER** > will appear.



Notice the time waveform data showing the decay of the response and the spectrum showing the resonant frequencies in this machine. Before hitting the structure again, wait for the message “waiting for trigger".



At the conclusion of the averaging process, the final averaged spectrum is displayed. Examine the data to see what frequencies are present.



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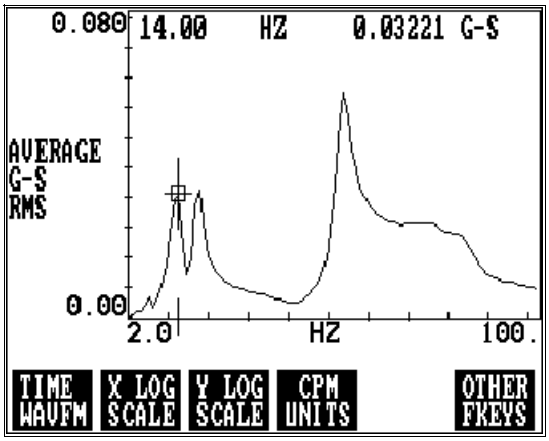
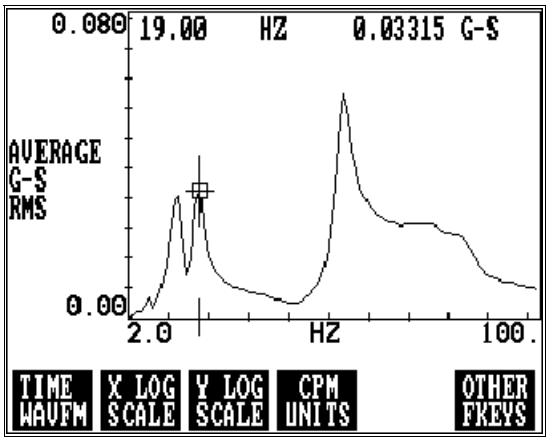
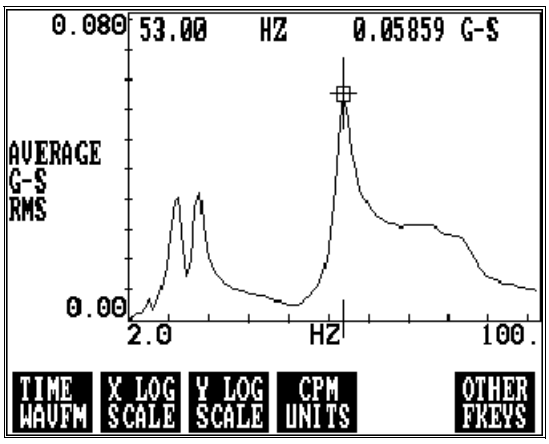
The first natural frequency is 14 Hz. The 19 Hz and 53 Hz frequencies are also natural frequencies.







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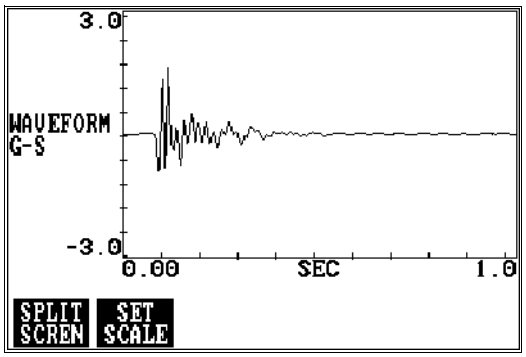
Notice the waveform data shows 10 percent of the time data before the analyzer was triggered.



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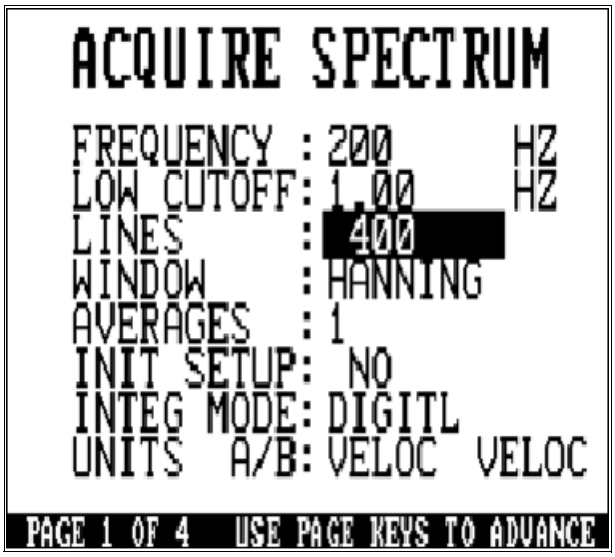
High Vibration Trigger

Have you ever attempted to freeze the Acquire or Monitor screens attempting to capture a random vibration spike? It's not an easy thing to do. A better method is to use triggering. In this case, it is not a tachometer signal that triggers the analyzer, it is a sensor signal.

If in the dual channel mode, two sensors can be placed at strategic points on the machine. One of the two signals will be used to trigger the analyzer to collect data. The assumption for this test is that the machine is operating in a normal manner and the trigger function will be used to catch a randomly occurring change in vibration.

Go to the Analyze / Acquire Spectrum function. Set-up the F_{max}, LOR as desired. Change the number of averages to one.



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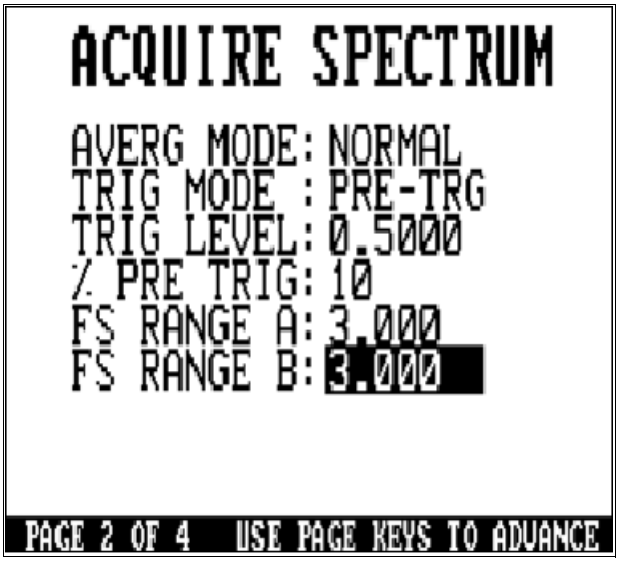
Page down to the Averaging and Trigger set-up page. Select **Normal** averaging. Either Normal or Pre-Trigger can be used to trigger the collection. If only using one accelerometer, then the trigger is on "A" channel by default. Set the Trigger Level to a value that is slightly higher than the current vibration level on channel "A" (you must already know what the current steady-state vibration level is). If PRE-TRIG was selected as the trigger mode, enter 10% as the % pre-trigger value. Set the F.S. Range for "A" and "B" channels to a level that is 2-3 times higher than the current (waveform) value.


ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : PRE-TRG
TRIG LEVEL: 0.5000
% PRE TRIG: 10
FS RANGE A: 3.000
FS RANGE B: 3.000
PAGE 2 OF 4 USE PAGE KEYS TO ADVANCE

Page down again and set the Active Channel to Dual channel.

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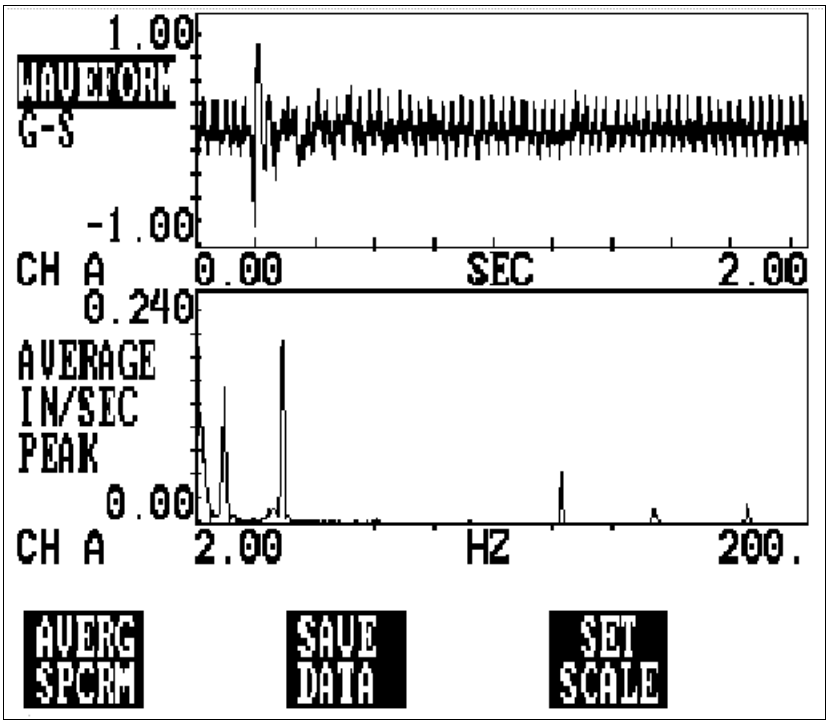
Press enter to start the measurement. The analyzer should display the message "Waiting for Trigger. If it does not, the trigger level will need to be increased. Once armed and waiting for trigger, the analyzer waits for the signal level to exceed the trigger before initiating a measurement.



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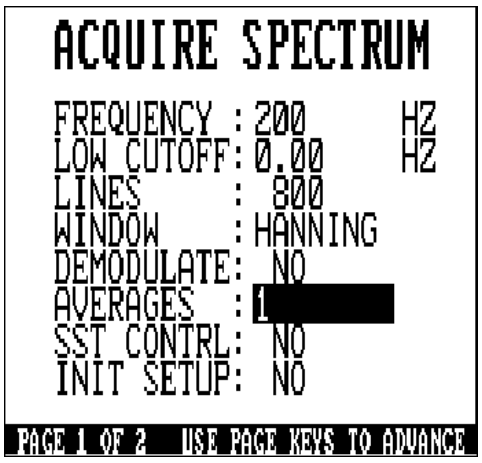
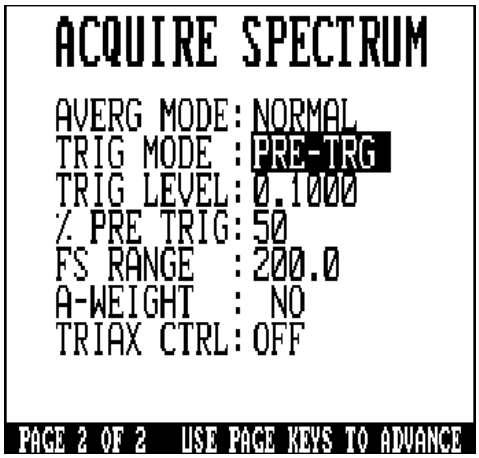
Current In-Rush Trigger

The 2120 analyzer can be used to measure other signals (besides vibration). Triggering on signal amplitude can be done for any signal measured on the analyzer. Examples are force, pressure, vacuum, speed, current, flux and vibration.

The following time waveform was collected from a laboratory machine setup. The machine was a motor coupled to a generator. The trigger level was set up to collect data once the incoming current reached 0.1 amps. Only one average was collected. The measurement collection time (T) is equal to the ratio of the line of resolution divided by the F_{max}. The F.S. range was set for 200 amps. By setting the full-scale range, the auto ranging process was bypassed, which allowed the data to be collected without delay as soon as the trigger level was reached. A pre-trigger of 50 percent was used to display the data. This setting tells the analyzer how far back in the buffer to go and pull data prior to the trigger.





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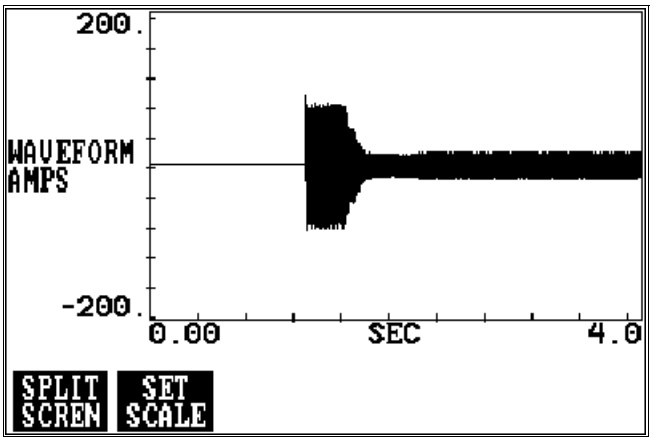
Current in-rush data may indicate machine faults. Amperage values at the initial surge reached a value of 91. Approximately half a second later the initial surge has leveled off to the normal operating current of 15 amps. It is very common for a motor to reach 5 to 7x normal operating current on startup.



Upon start-up, an induction motor must overcome a large amount of torque. Current is high at start-up. As the motor reaches operating speed, the current begins to drop off. If an in-rush test was found to be too high or did not drop off in the appropriate amount of time, something is wrong with the motor. The problem could be related to supply voltage, a problem with the motor windings, a foreign object causing a binding, or a tight or binding bearing.

The current in-rush test is usually not performed on a routine basis. It is more of a diagnostic tool.

Trigger Lab

Set-up the analyzer and collect triggered data for the following conditions:

1. ·· Single channel impact test

2. ·· Increasing vibration amplitudes

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Review

Triggered data capture is a useful technique for a variety of measurements. A trigger causes the analyzer to take a measurement. In the absence of a trigger signal, the analyzer measures at its own pace based on the F_{max}, lines of resolution and overlap settings.

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Resonance Detection

Section 10

Objectives

- Define natural frequency, resonance, and discuss how resonance affects machine vibration
- Understand the three parameters that affect the amplitude and frequency of the resonance
- Discuss when to test for resonance
- Review the single-channel analysis tools available for diagnosing resonance

CSi means Reliability Training

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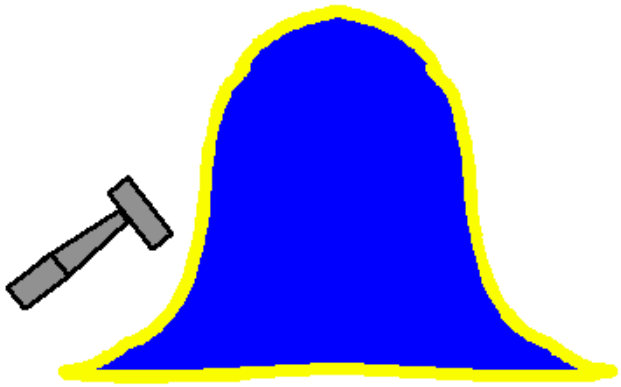
What is a Natural Frequency?

Every part of a machine has natural frequencies. A **Natural Frequency** is the frequency that a part likes to vibrate when excited by a single input force. For example, when a bell is struck, it vibrates at its natural frequency.



Machines and structures have many natural frequencies. When parts are assembled, the assembly takes on new natural frequencies based on the mass, stiffness and damping of the machine.

Any force, momentary or periodic, with energy in the range of a component's natural frequencies, will cause the component to vibrate at its natural frequency.

The input force can be an impact from a bump, check valve or process upset or it may be a periodic force such as unbalance, misalignment or other mechanical faults. If energy is present near a natural frequency, the system will respond.

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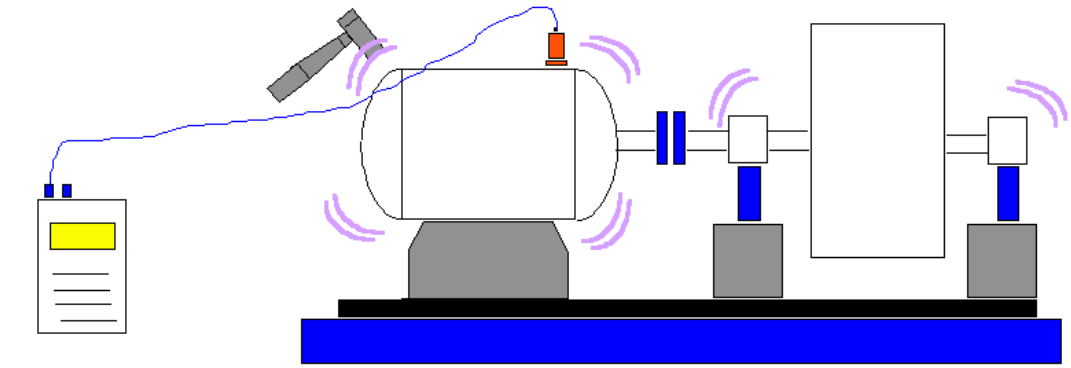
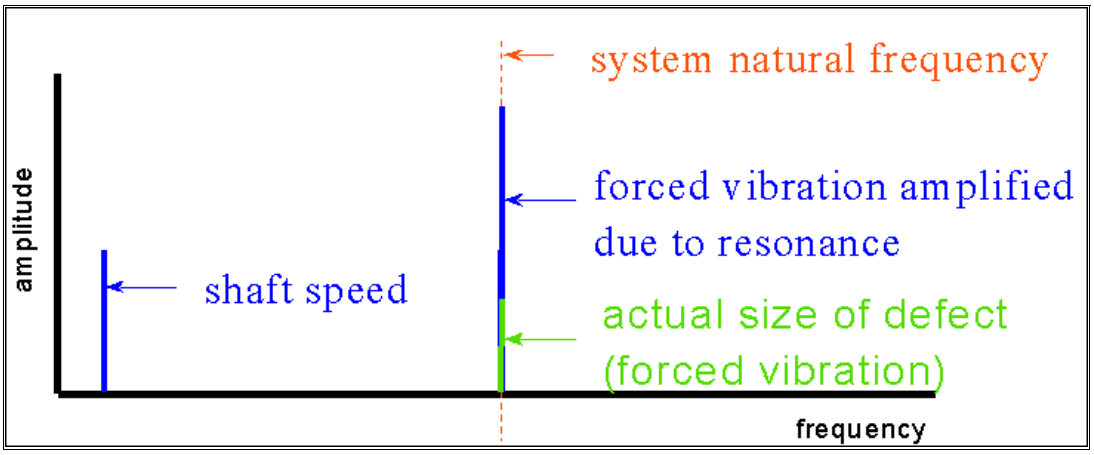
What is Resonance?



Resonance is defined as a natural frequency that is excited by a nearby forcing function, like unbalance. All mechanical systems have natural frequencies which, if excited by a forcing frequency, will result in greatly amplified vibration on the machine. Several factors work together allowing resonance to occur, such as low stiffness and/or low damping at the resonant frequency. Resonance is not necessarily a problem unless machine defects create vibration or nearby machinery transmits vibration at the same frequency as the resonant frequency.

Resonance does not create vibration; it only amplifies it.



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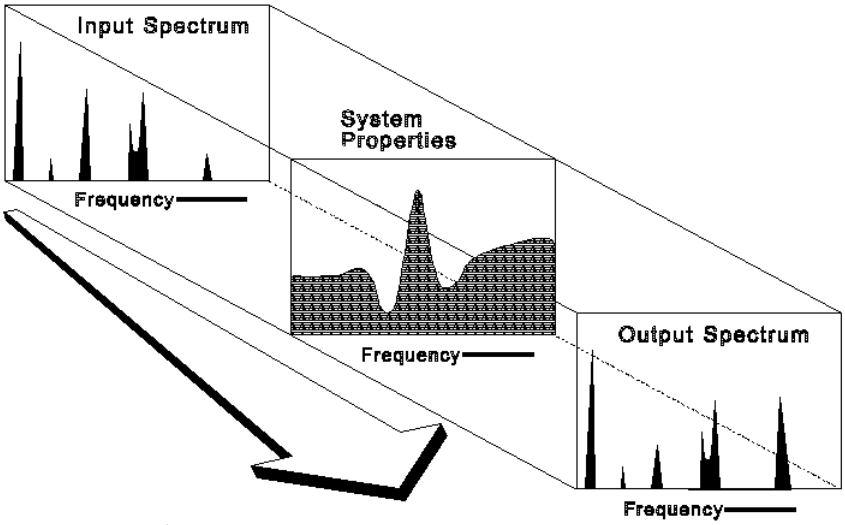
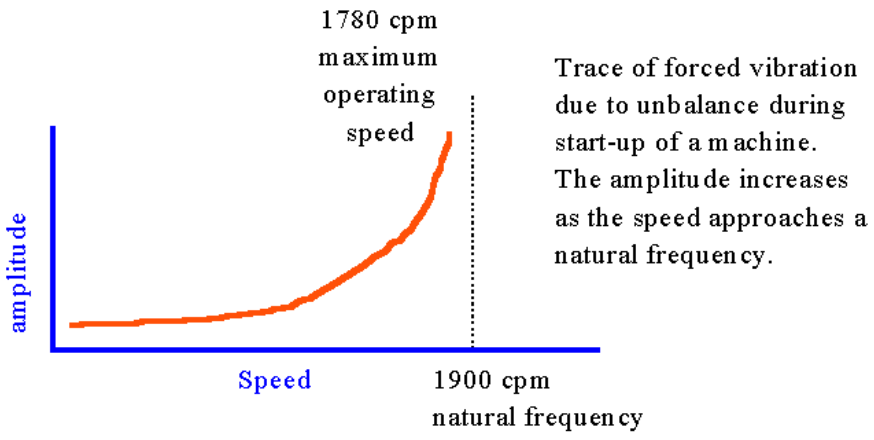
Frequency Response and Transfer Functions



Resonance is not itself a defect, but it is a property of the whole mechanical system. The mass, stiffness, and damping of the system at each frequency determine how the system will respond to the forces acting on it. If the natural frequency is not excited by some forcing function, resonance will not be a problem. Think of this like a bell or a drum. The bell possesses the potential to resonate at a particular frequency (or frequencies) if it is excited by the clapper. If it is not excited, then it does not vibrate at its resonant frequency.

Resonance is an amplifier. Small input forces result in large output vibrations. The closer a forced vibration is in frequency to a system's natural frequency, the more amplification there will be.



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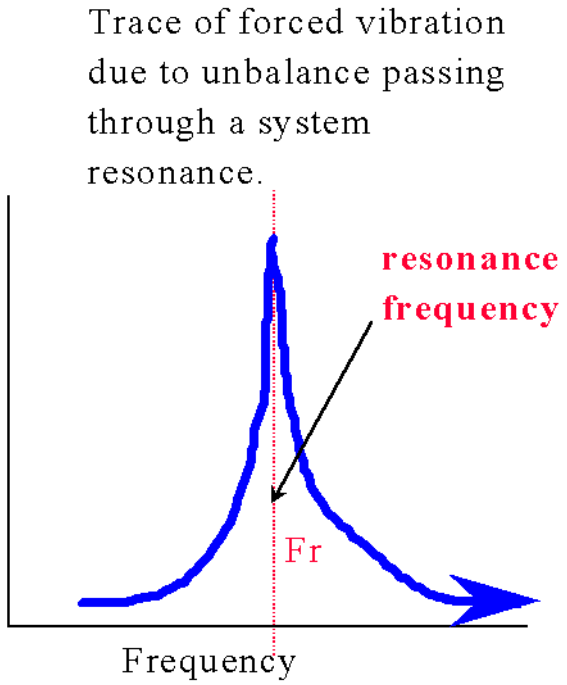
In the example above, a 1800 rpm shaft that is started from zero speed. Assume that a system natural frequency exists near 1900 cpm. A small amount of unbalance in the shaft will be amplified as the rotor speed approaches the natural frequency. Since full speed (1800 rpm) never reaches the natural frequency, the vibration due to unbalance increases as the rotor approaches full speed. If the natural frequency were below the operating speed of the rotor, the vibration due to resonance would peak out and then return to normal levels.



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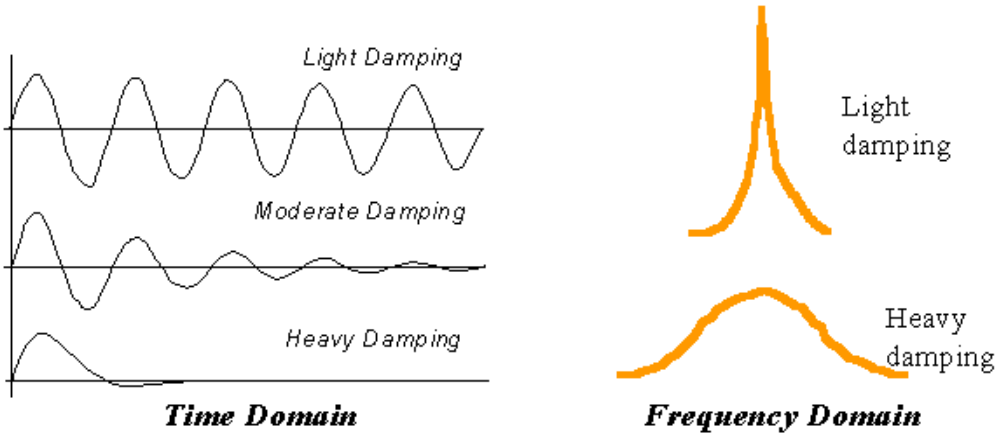
The amount of amplification at resonance depends the amount of input force and the system's damping characteristics. To demonstrate how damping affects resonance, assume an impact test is performed on a machine. A lightly damped machine will ring like a bell for a long time and produce a tall, sharp spike in the frequency spectrum. A heavily damped system, like the spring and shock absorber combination on an automobile, rings for a shorter time and produces a smaller but broader peak in the frequency spectrum.



Resonance is a property of the machine whether running or not. Be aware that the dynamic shaft stiffness when the machine is running may be different enough from the at-rest static stiffness to cause the resonance to vary slightly. The **rule of thumb** has always been that a resonant frequency measured with machinery shut off should be at least 20 percent away from any forcing frequency.

As mentioned before, individual parts of a machine have resonant frequencies such as shafts, rotors, casings, and foundations. When these machines are assembled, these resonant frequencies shift because of the mass, stiffness, and damping effects that occur when the machine is put together. Also, dynamic stiffening effects may shift the static resonant frequencies when the machines are running at their operational speed.

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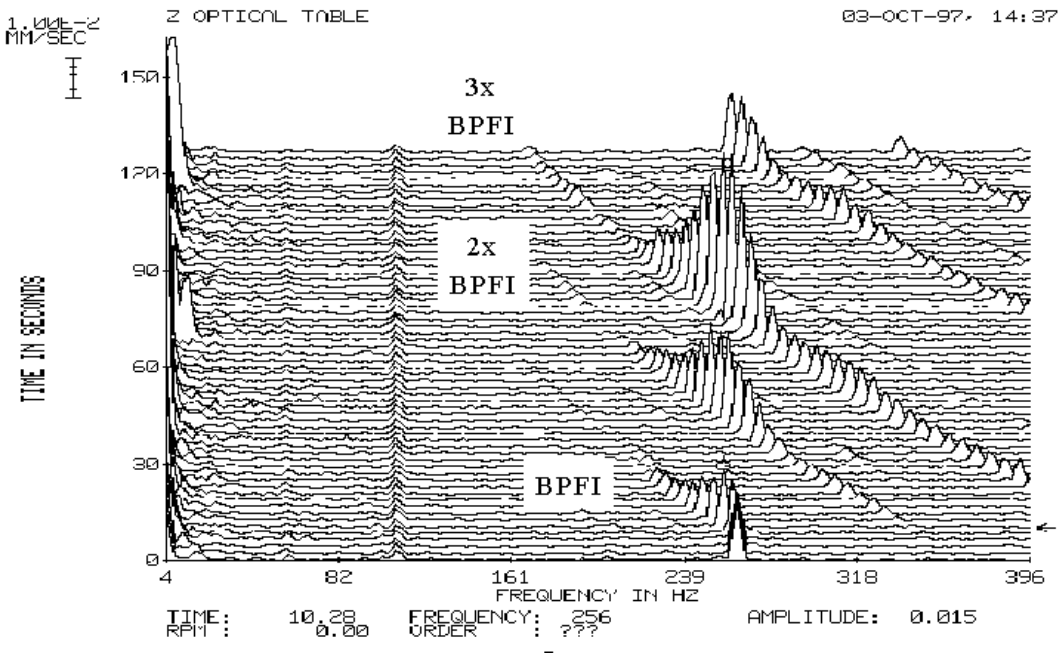
Resonance may be observed as a machine starts up and runs through a resonant frequency. The amplitude of the 1xTS will increase to a maximum amplitude at the resonant frequency and decrease as it passes through the resonant frequency. The example below shows the coastdown of a high speed rotor. A bearing defect at ball pass frequency of the inner race (BPFI) is present along with harmonics. As the shaft decreases in speed, the vibration at BPFI increases due to resonance at about 256 Hertz. As the machine continues to slow down, the harmonics of BPFI passes through the 256 Hertz resonance and are also amplified.



As machines wear and clearances change, resonances often shift close to operating frequencies. An unexpected defect frequency, such as a harmonic of looseness or some other machine defect may excite a resonant frequency

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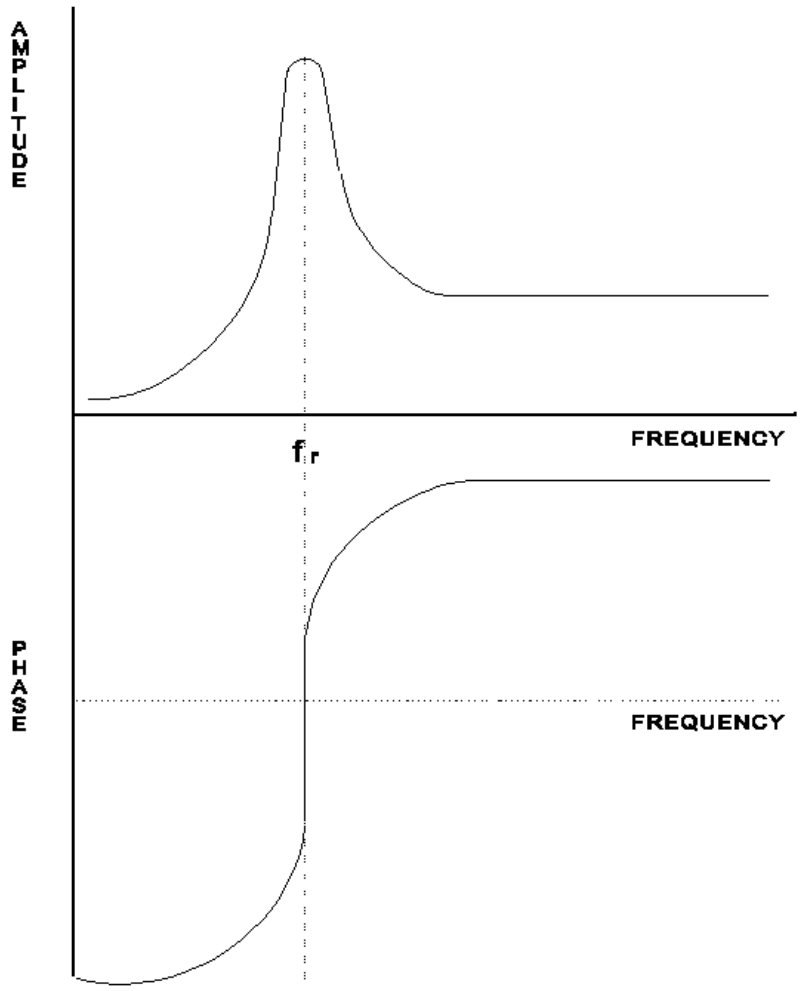
The phase will go through a 180E change as the shaft passes through resonance with a 90E phase shift occurring at the resonant frequency. (The 180E phase shift often only occurs on simple single-plane types of rotors. More complex shaft/rotor systems exhibit a phase shift, although not 180E.)



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What is a Critical?

A critical is a special case a resonant frequency that occurs when a rotor's rotational speed is the forced vibration coinciding with one of the rotor's natural frequencies. Most rotors have natural frequencies that are well above the rotational speed. Large rotors, like turbines, may have one or two natural frequencies below operating speed. During the start-up of turbines, it is essential for machine operators to know where the natural frequencies are and to pass through those speed ranges as quickly as possible. When a rotor rotates at a frequency near or at one of its natural frequencies, the rotor is said to be "at critical". At critical, tremendous amplification is possible resulting in severe damage to the machine and possible failure.

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What Causes Resonance?

Competition ñ Machines are built smaller and lighter that they were years ago. The differences in mass, stiffness and damping has shifted natural frequencies around in the spectrum. In many cases, the natural frequencies are now closer to the forced vibrations ñ increasing the probability that resonances are encountered.

Wear - As a component wears, its stiffness changes resulting in a change in natural frequency.

Customer Demand - So many production machines have been sped up for increased production. Often, little attention is given to individual machine components where the natural frequencies are with respect to the new speed.

Internal Vibrations - All forced vibrations on a machine have the potential to excite resonance.

External Vibrations - All transmitted vibrations from other sources have the potential to excite resonance.

Noise - Noise is airborne vibration. Sounds will excite natural frequencies as easily as structure born vibrations.

Air Pulsations - Movement of air can easily excite a natural frequency. Ductwork vibrations is one example

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Measuring Resonance

Resonance testing should be performed whenever vibration levels or spectral patterns cannot be explained by forcing frequencies. When diagnosing a high amplitude vibration problem, the analyst needs to consider the possibility of acceptable vibration exciting a resonance and causing unacceptable levels of vibration.

Several techniques can be used to detect resonance. Most are single channel techniques. The most common single channel resonance tests include:

- Negative Averaging
- Bode Plots
- Peak hold averaging
- Cascade Plots
- Operational Deflection Shape (maybe)
- Single Channel Impact

Negative Averaging

Negative averaging is a very powerful technique that has the capability to subtract energy from a previously collected, normally averaged spectrum. Negative averaging is the only good way of detecting resonance on an operating machine. The way negative averaging operates is to dynamically subtract the "noise" (as defined for the job) from two spectral measurements. The "noise" is basically, any signal that appears in both spectrums. For example: In the first measurement, a machine is operating normally and is also impacted for resonance. In the second spectrum, the machine is operating normally. The negative averaging process subtracts the two leaving only the data resulting from the impacts. The overall reduction of those amplitudes defined as noise is proportional to the square root of the number of averages.

Normal Operation + Impacts - Normal Operation = Data from Impacts

To perform Negative Averaging follow these steps:

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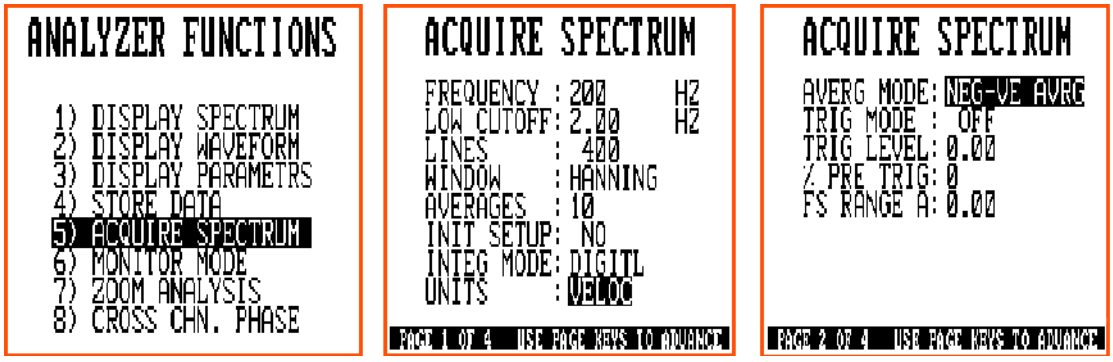
Collect data in the acquire spectrum mode with negative averaging selected. The analyzer will take the first data set in normal averaging. (All data receives the same weight.) Ten averages should be enough. During the averaging, the machine is operating normally. In addition, impact the machine with a rubber mallet or block of wood. If hanning weighting is used, impact the structure several times to be certain that the impact has been properly measured. Use 1-2 second intervals for the impact. Just be sure the machine has enough time to "ring down" before striking again. If uniform weighting is used, it is only necessary to impact the structure 1-2 (or more) times during the averaging.

2120 Set-up for Negative Averaging



The first data set in normal averaging is stored in a buffer until the second data set is subtracted from the data contained in the buffer.

At the end of the predefined number of averages, the analyzer will stop and display the message, **Begin the negative averaging process by pressing Enter**. At this time, the machine is operating normally with no impacting. As the averaging begins, any signal that was present in both sets of averages will begin to average out of the spectrum. The averager will not stop until the enter button is pressed. Continue averaging until no additional change is seen in the spectrum. Press Enter to stop averaging. Store the final spectrum if desired.

The plot shown below is the result of Negative Averaging. The peak indicates a natural frequency at 3500 cpm. The peak at turning speed (3570 cpm) was removed through negative averaging. Notice how the 1x peak cut a notch through the spectrum. The notch is visible only because it cut through the amplification curve of the natural frequency. The width of the amplification curve gives an indication of the amount of damping.

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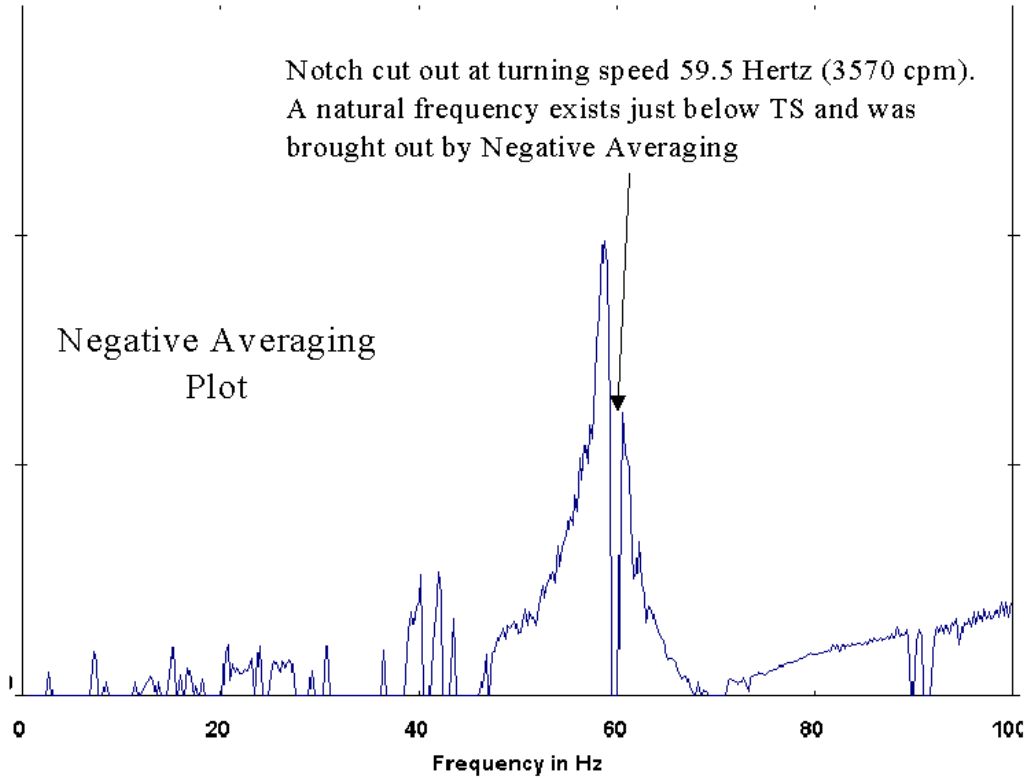
Estimate how much higher or lower the current operating speed needs to be changed to avoid large amplification due to resonance?



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Monitoring Peak and Phase Data (Bode Plots)

The monitor peak/phase function defines the location (in degrees) of a machine's vibration peak with respect to a fixed reference mark on the rotor. Monitor Peak/Phase can be used for phase analysis and resonance detection. Within the context of this lesson, we will discuss using Monitor Peak and Phase for resonance detection during machine coastdown or ramp-up

Vibration alone indicates the magnitude and frequency of vibration. Adding phase to the analysis of vibration data gives the direction of vibration. If the vibration frequency, magnitude and direction are known, a phase analysis can be performed. Phase analysis reveals the directions components are moving in relation to each other. Phase also reveals information about specific mechanical faults. For example, phase may confirm suspected unbalance, misalignment, looseness or other faults. Phase is used to confirm resonance. The phase characteristics of resonance might include unstable phase readings, unexplainable phase relationships, phase shifts during startup or coastdowns and component bending.

To complete a phase analysis using monitor peak/phase, it is necessary to measure, record and analyze the phase and magnitude values from the monitor peak/phase screen. Data must be measured at each (synchronous) frequency of interest on each bearing in the horizontal, vertical and axial planes.

If monitor peak/phase is measured during a coast-down or ramp-up, the changes in magnitude and phase can be studied and evaluated for resonance. The steps outlined below describe using monitor peak/phase for resonance detection.

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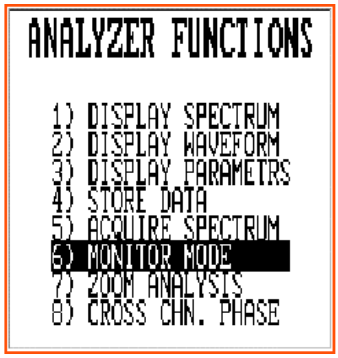
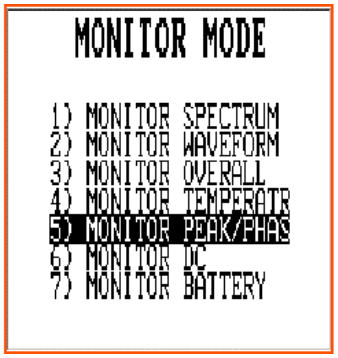
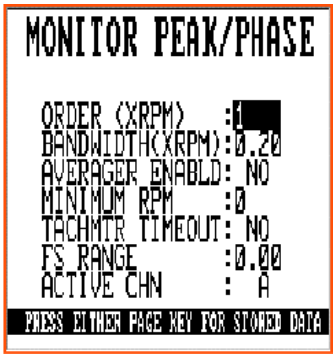
Place a sensor on the machine at the position of interest. Use a tachometer to measure shaft speed and connect the tach signal to the tachometer port on the analyzer. The machine should be in operation. Set up the 2115/2120 Monitor Peak/Phase screen as shown below.

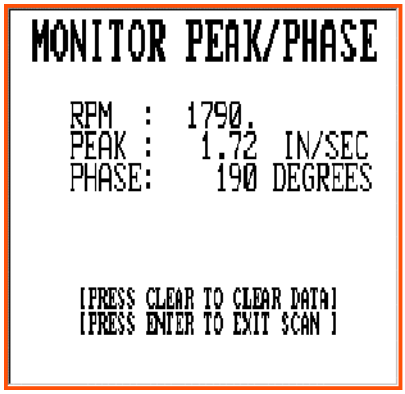


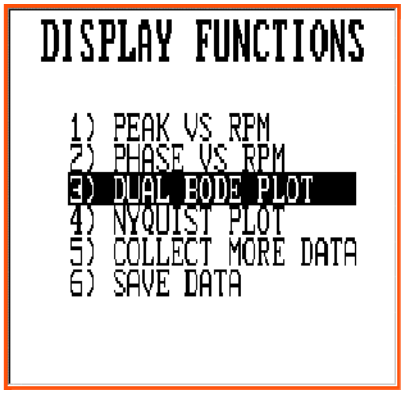




Start the measurement and let the machine coast down. The rpm, phase and magnitude changes can be viewed from the Monitor Peak/Phase display screen. When the shaft has slowed to a few rpm, press the Enter key to stop the measurement. The Display Functions screen has several options for data display as well as saving data.

Monitor Peak/Phase Measurement and Display





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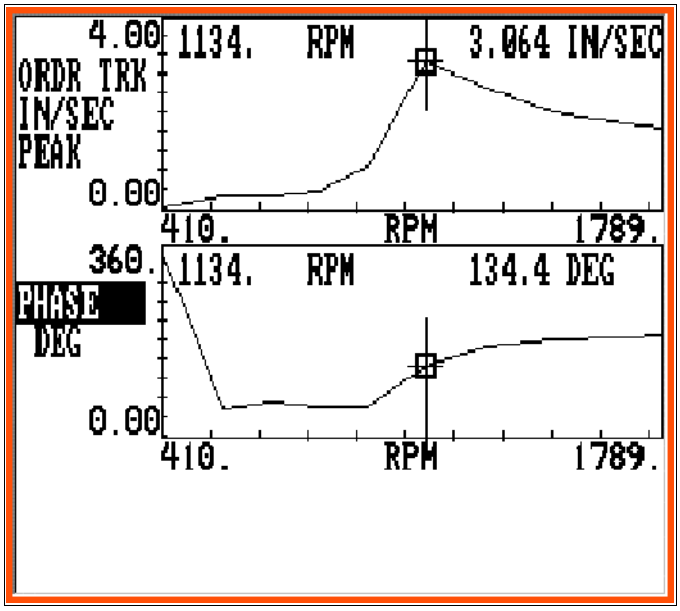
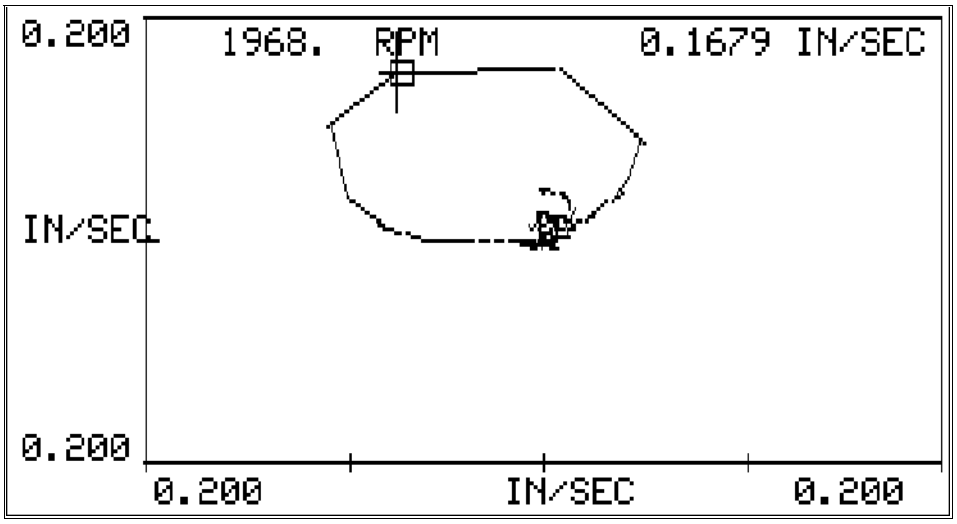
The data plot below is a Bode plot. A Bode plot is a rectangular plot of peak vibration magnitude and phase vs. speed. The data below indicates that during coastdown, the vibration magnitude peaked out at 1134 rpm. At the same time, the phase reading changed approximately 180E through the amplification area. Phase at the resonance peak is 90E out of phase with data that is off of the amplification curve on either side. This combination of events proves, without doubt, that a resonance is present at 1134 rpm.



A Nyquist plot is the same peak and phase data viewed in a polar plot format. As the phase changes rapidly near resonance, it traces out a circle on the polar plot. Each loop in the plot is a resonant frequency.



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Bode plots and Nyquist plots show important information about resonance. The presence of run-out or a bow in the shaft, however, can significantly alter the appearance of Bode plots. Nyquist plots, on the other hand, remain unaffected by run-out and bowed shafts. Always use Nyquist plots to confirm any conclusion based on Bode plots.

Peak-Hold Data Collection

The Peak-hold averaging function retains the highest amplitude at each line of resolution. It is most commonly used for coastdown data when a tachometer signal is not available. Peak-hold averaging can also be used when amplitudes are unstable from sample to sample.

Set up the Acquire Spectrum menus as shown below. The number of averages will depend on the time it takes the machine to coast down and the configuration of the analyzer. Three items control how long it takes the analyzer to process data. They are:

- the frequency span of the measurement
- lines of resolution
- Signal Overlap.

Without optimizing the analyzer's processing speed, the peak hold coastdown plot could look like what is called "picket fencing". This condition is simply missed data during the coast-down. In picket fending, the spectrum looks like a series of peaks rather than a smooth trace of the coast-down.

Overlap: In the Utility menu/Change set-up/Measurement Control, change the overlap from the default value of 67% to 99 percent. This means that after the first average, the analyzer will use 99% old data and 1% new data for every average. This results in a faster processing speed.

> ***Note***
> *Don't forget to change the overlap back to 67% after the peak-hold test. This field is not controlled from MasterTrend or RBMware programming.*

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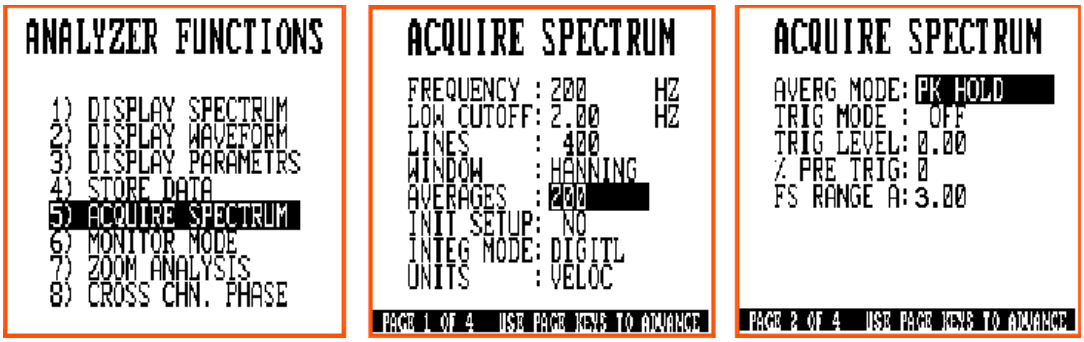
Frequency Span: Choose a frequency span that places the frequency of interest away from the left edge of the spectrum without sacrificing analyzer speed (*lower frequency spans mean longer data acquisition time*).

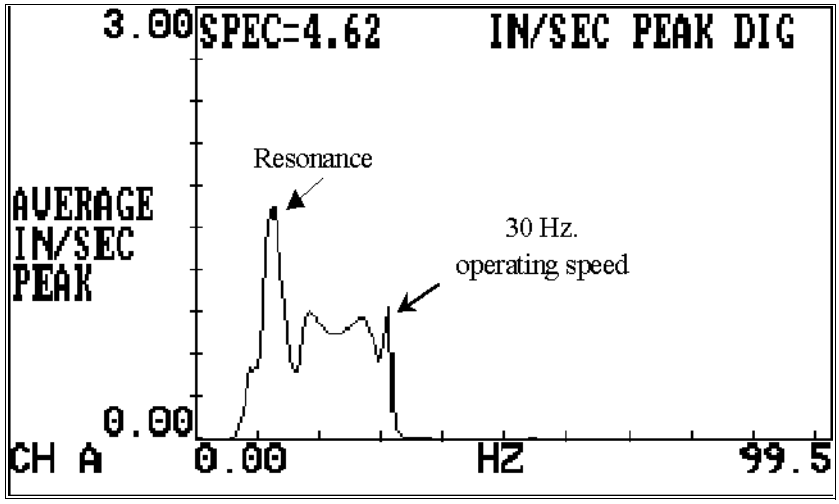
LOR - Use 100 - 400 lines of resolution. In peak hold coast-down testing, it is not important to have high resolution to identify resonance.

Number of Averages: You may not know how many averages are required to collect the entire coastdown. Enter a large number of averages like 2000 into the field. If the machine has stopped before averaging is complete, press the ENTER button to end the measurement.

Page through the set-up screens. Select **Peak Hold** averaging and no trigger on page 2. Press **Enter** twice to acquire the data. Shut down the machine when your analyzer starts displaying a spectrum.



An example Peak Hold Averaged Spectrum is shown below.



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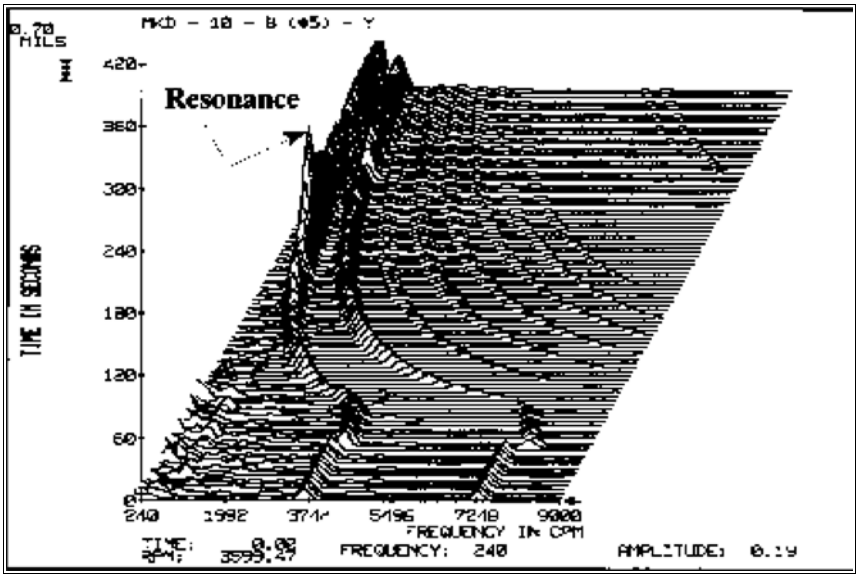
If any vibration frequency passes through a resonance during coastdown, its amplitude will peak - suggesting a resonance. Resonance is not proved completely unless phase is measured as in a Bode plot.

Cascade Plots

Cascade or ***Waterfall Plots*** provide a three-dimensional view of the coastdown or startup data. A finite number of spectra are stacked over time. The vertical axis can be Time or RPM. If the cascade data is collected without the aid of a tachometer input, then Time becomes the only available option. The cascade plot shown below shows the coastdown of a 100+ megawatt gas turbine that passed through a resonance (critical) during its shutdown.



Operating Deflection Shapes

The purpose of Operating Deflection Shapes (ODS) is to provide insight into the way the machine structure is moving under operating conditions. This method of data acquisition and modeling of the machine's motion may provide insight to a resonant condition. Remember that ODS's are not mode studies and do not prove resonance. ODS's display the motion of the machine using forcing functions. To prove resonance suggested by ODS, the analyst must perform a test for resonance such as an impact test. Once resonance is confirmed, an Modal Analysis Survey may be needed.

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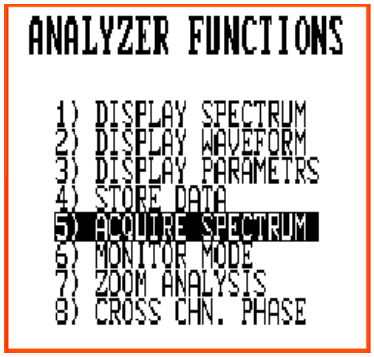
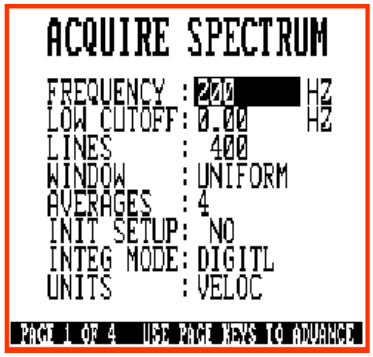
Single Channel Impact Testing

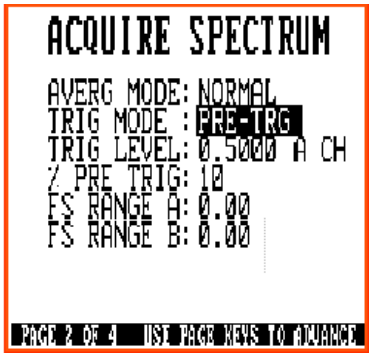
In single channel impact testing, a sensor placed on the machine, measures the structure's response to an impact from a rubber tipped mallet, block of wood or other object. The mass and hardness of the impact device determines how many natural frequencies are excited. An impact test identifies natural frequencies. It does not indicate the shape of the structure at resonance or how to correct a resonance problem.

Resonance is directional and can be localized. It is important to impact different locations on the structure.

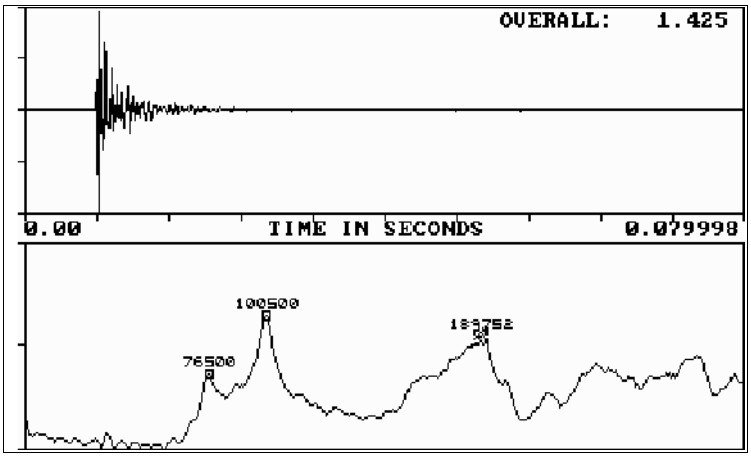
There are many ways to measure impact data on the 2115 or 2120 analyzer. The best way is to trigger the analyzer based on the amplitude of the channel "A" signal. In other words, the analyzer takes the measurement when it senses the impact. The screens below show the Acquire Spectrum set-up screens.






ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : PRE-TRG
TRIG LEVEL: 0.5000 A CH
% PRE TRIG: 10
FS RANGE A: 0.00
FS RANGE B: 0.00
PAGE 2 OF 4 USE PAGE KEYS TO ADVANCE

The 10% pre-trigger moves the impact away from the left edge of the time window by 10% of the total time.



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When performing single channel impact testing, the full-scale (FS) range function setting should be considered (page 2 of the set-up screens). A zero entered in the FS range field causes the analyzer to autorange. Using the autorange feature may require several test impacts so that the analyzer can select the proper range. If a number is entered into the FS Range field, the analyzer's input buffer is set to receive signal up to that level before a signal overload occurs. A potential for poor signal to noise ration exists if the number entered is too high. The units for the FS range field are Waveform units.

Signal Integration Effects

Better results are usually obtained when the waveform is not integrated for an impact test. Integration filters and smooths the signals thereby reducing the spikes or impacts in the waveform. An acceleration waveform, using an accelerometer, is ideal for most cases because acceleration has greater sensitivity to impacting than velocity or displacement.

The spectrum of the impact can be viewed in acceleration, velocity or displacement. Analog or Digital signal integration can be used if the sensor "convert to" units is Acceleration. Either integration type results in an Acceleration waveform. If the sensor "convert to" units is set to Velocity or Displacement, the signal integration type needs to be Digital so that the waveform remains in Acceleration. Digital integration only changes the spectrum to the "convert to" units.

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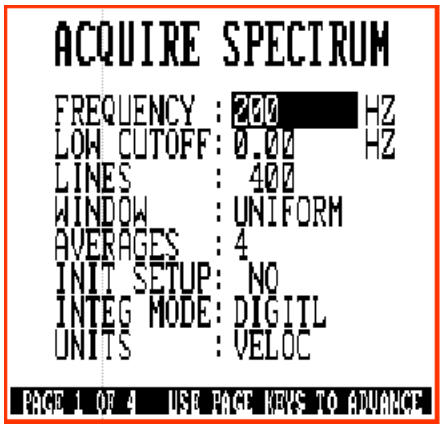
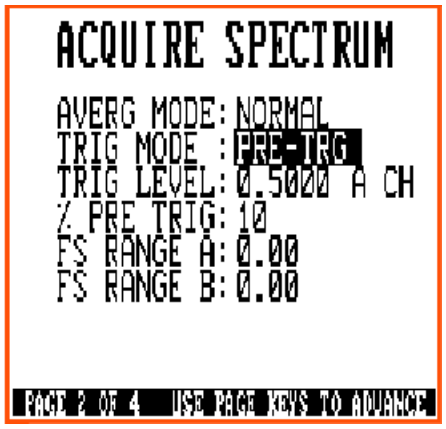
Assume that the sensor is configured as an accelerometer converted to velocity. The analyzer set-up screens below, indicating Digital Integration and Velocity Units, cause the analyzer to measure an acceleration waveform and a velocity spectrum. The Trig Level setting of .5 on Ch "A" cause the analyzer to wait for a signal amplitude of 0.5 G's on channel "A" before acquiring an average. Pre-Trig results in a waveform display where the impact begins at 10 percent from the right edge of the time window.




ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : PRE-TRG
TRIG LEVEL: 0.5000 A CH
% PRE TRIG: 10
FS RANGE A: 0.00
FS RANGE B: 0.00
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Window Functions

The window function shapes the input data to compensate for discontinuities in the sampling process. The function is applied to the waveform signal before computing the FFT spectrum. The CSI 2120 analyzer has two window functions to choose from: Hanning and Uniform. Uniform windowing should be used for impact testing.

Hanning - The Hanning window smooths out end effects and reduces a digital signal processing error called leakage in the spectrum. Hanning window is recommended for normal analyzer operation where periodic data is being measured.

Uniform - The Uniform window option does not apply any shaping. It does nothing to the waveform. Data acquired with the Uniform window is subject to leakage and amplitude errors. Uniform window should be used for transient signals that are completely contained in the analysis time record length.

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The Advanced Two-Channel DLP offers two additional window functions: Force and Exponential windows. The Force and Exponential Windows are really two separate window functions used for dual channel impact testing and modal analysis. The settings for these windows are adjustable.

Force - The Force window creates a window that isolates the hammer impact to exclude background vibrations.

Exponential - The Exponential window shapes the response to the impact measured by an accelerometer.

Averaging Modes

There are many averaging methods. For impact testing, two techniques can be used. They are:

1. ··Normal averaging

2. ··Peak hold

Normal averaging provides the analyst with the ability to average out noise and other inconsistencies during impact testing. The best choice for impact testing is normal averaging when triggering is also used. Three or four averages are all that is needed for impact testing.

Peak-hold is referred to as averaged data. However, the peak-hold data collection method does not average. Instead, the highest amplitude at each line of resolution is kept while all others are discarded. Double hits, noise and other signals can ruin peak hold averaged data. For that reason, care must be taken when Peak-hold averaging is used for impact testing. Peak-hold averaging works well when triggering is NOT used during impact testing. One or two averages is all that is needed.

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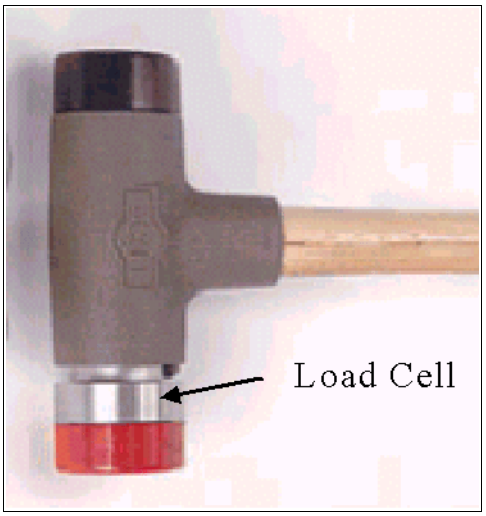
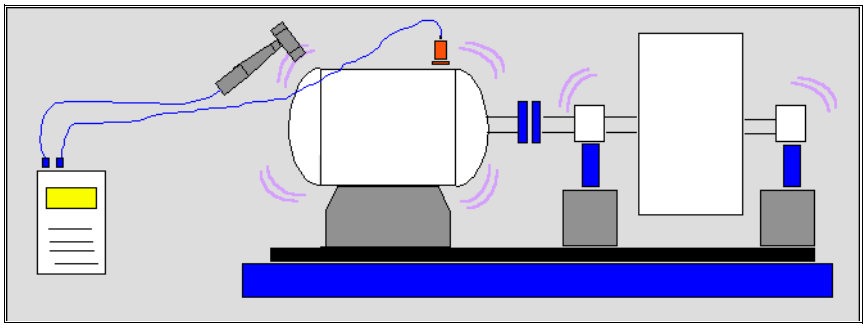
Dual Channel Impact Testing

Impact testing is best completed using a multichannel analyzer to simultaneously measure impact and response data. In a dual channel impact test, a force hammer is used to deliver energy into the machine or structure. Force hammers are instrumented with a load cell. The sensor measures the Force of the impact in Pounds. Phase, coherence and the transfer function are products of a cross-channel measurement. (Coherence is a dual-channel function that relates how much of the input signal caused the output signal.) This means that resonance frequencies can be identified more accurately.

Impact hammers are instrumented with load cells. The load cell measures the impact force in the hammer when the machine is struck. The amount of energy transferred into a structure depends on the size of the hammer. The amount of frequency put into the structure is determined by the hammer tip hardness.



When a machine is hit with an impact hammer, broad band spectral energy is input into the machine. The impact excites the machine's natural frequencies.



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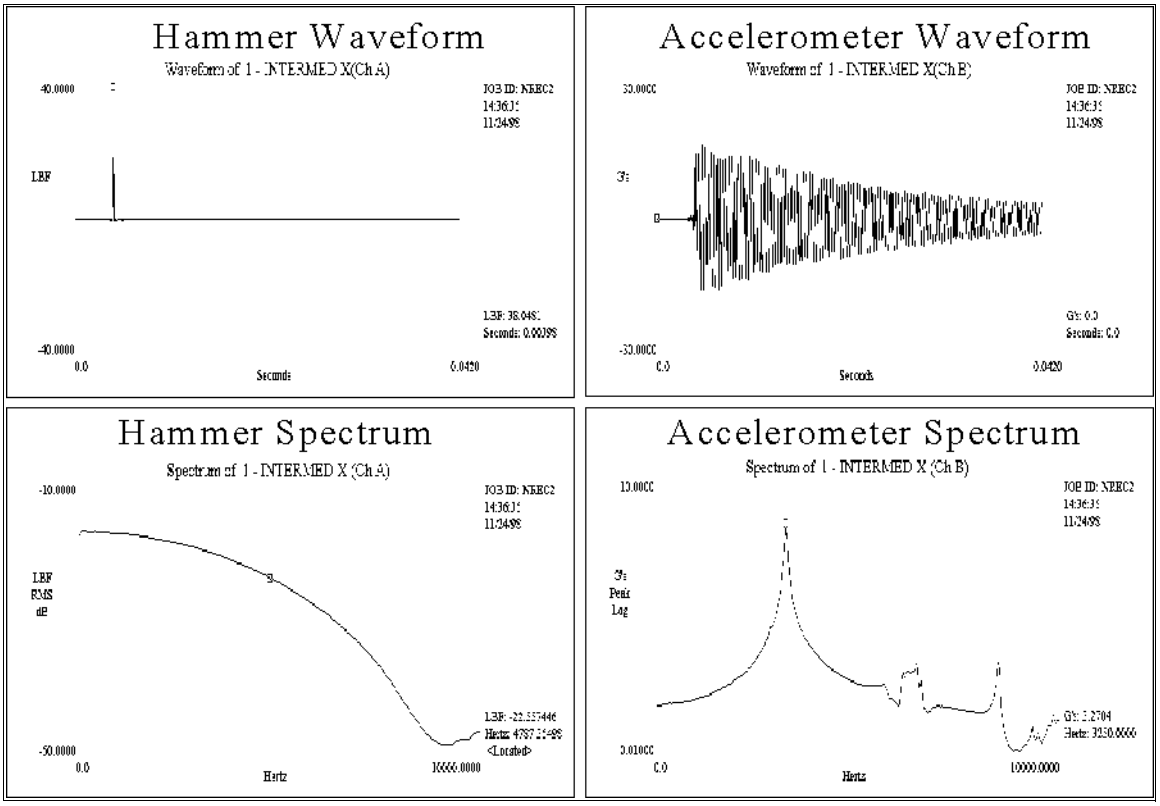
The machine's response to the impact is measured with one or more accelerometers. Each natural frequency that is excited, "rings" then the vibration decays quickly and disappears. The machine's internal damping determines how long the machine rings in response to the input force. The picture below shows an example of impact test data.

Channel A Input **Channel B Response**



The hammer waveform shows a typical impact measured by the load cell on the hammer. It is a sharp spike (positive or negative depending on the orientation of the hammer. The impact produces low level energy over a broad frequency range.

The hammer spectrum shows the frequency response of the hammer tip. Notice how the hammer force decays at the higher frequencies? The hardness of the tip determines how much frequency is delivered. Hammer response spectrums are typically displayed with Log/Log axes scaling. For modal testing, choose a hammer tip that delivers energy out to the maximum frequency of interest. The hammer spectral amplitude should not drop more that 3dB over the range.

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When the impact is delivered to the machine, the natural frequencies of the machine are excited and resonate. The response accelerometer waveform shows the ring-down and the accelerometer spectrum shows each natural frequency.

Two, 2120-2 dual channel impact testing measurement methods are discussed in this section:

Impact testing using standard functions of the 2120-2 analyzer

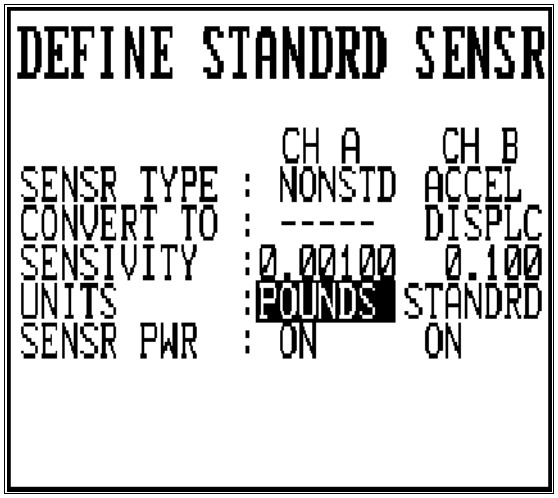
Impact testing using the Advanced 2-Channel DLP

1. Dual Channel Impact testing using 2120-2 Standard Features

There are two ways to measure dual channel impacts using the 2120-2 analyzer in its standard configuration. In the ANALYZE mode, either **Monitor Spectrum** or **Acquire Spectrum** can be used for the measurement. Connect a force hammer to channel "A" and an accelerometer to channel "B".

Check that DUAL CHANNEL has been enabled on the analyzer by pressing UTILITY, CHANGE SET-UP, MEASUREMENT MODE. Make sure the dual channel mode is set to ON.

The sensor set-up screen, located in Utility must be changed to accommodate the force hammer. Press UTILITY, CHANGE SET-UP then SENSOR TYPE.



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Since there is not a Force Hammer sensor type, NONSTANDARD must be used for channel "A". Enter the sensitivity of the hammer in volts/pound, type in POUNDS as the unit of measure and turn sensor power ON. Press enter when finished.

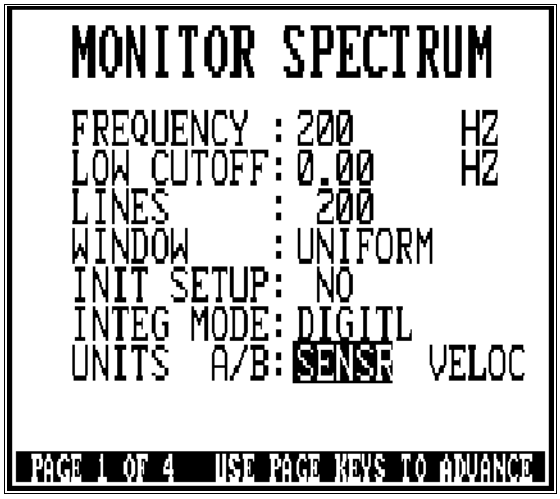
Note

If a route is loaded and active on the analyzer, do not press the RESET button at any time after changing the SENSOR screen. Pressing Reset, with a route active on the analyzer, changes the sensor screen back to the sensor settings required by the route point.

Dual Channel Impact Testing in the Monitor Spectrum Mode

Note

Make sure the sensor set-up is configured as shown above and if a route is active on the analyzer, do not press reset at any time after changing the sensor screen.



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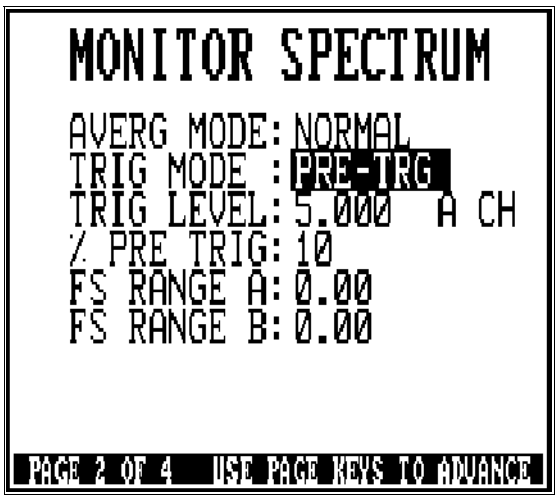
The analyzer setup for dual channel impact testing using the **Analyze/Monitor/ Monitor Spectrum** mode is shown below. The units for channel "A" must be sensor. The units for channel "B" can be acceleration, velocity or displacement. Uniform windowing should be used when measuring impact data. Keep the lines of resolution at 200 or 400. High lines of resolution are not necessary for impact testing unless closely spaced peaks must be resolved.Page down to configure the trigger settings.

Since the impact data is random, a trigger is needed to allow the analyzer to begin measurement when the impact occurs. The trigger mode should be NORMAL or PRE-TRIG. PRE-TRIG (pre-trigger) is a better choice, when in the Acquire Spectrum or Monitor Waveform modes. The Monitor Spectrum Mode does not permit viewing waveforms although, using PRE-TRIG does not affect the measurement in Monitor Spectrum. Set the trigger level at 5 pounds to trigger off of channel "A" with a pre-trigger of 10%. Five pounds should be enough force to prevent the analyzer from triggering until the hammer hits. If the FS range values are left at zero, the analyzer to auto-range the incoming signals. It will take a few extra hits for the ranging to complete.


MONITOR SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : PRE-TRG
TRIG LEVEL: 5.000 A CH
% PRE TRIG: 10
FS RANGE A: 0.00
FS RANGE B: 0.00
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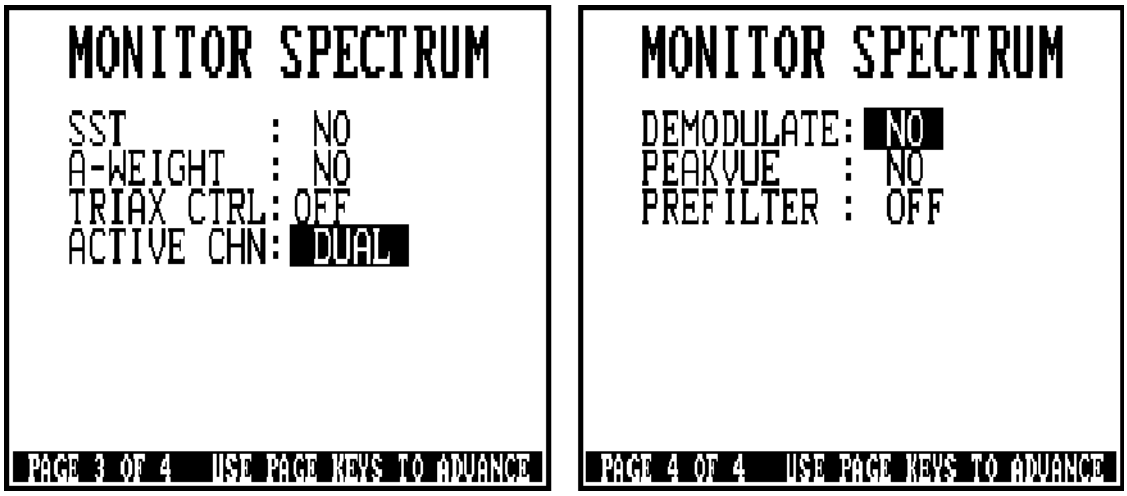
Page down and make sure the ACTIVE CHANNEL is set to DUAL.



Press ENTER to begin the measurement. The analyzer ranges and display the message "waiting for trigger". Impact the machine and follow the commands displayed on the 2120. It may take a few impacts for the analyzer to range properly. Try to maintain the same impact force or the analyzer will overload and have to range again.

Since the measurement was made in the Monitor mode, there is no averaging. A new measurement is made each time an impact of more than 5 pounds occurs. The measurement will not end and cannot be saved. It can be printed from the analyzer using the Virtual Printer program.

The analyzer display shows the instant spectrums of channels "A" and "B".

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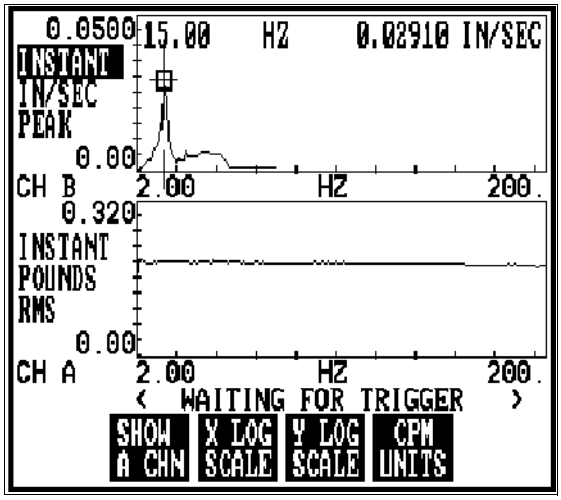
The picture below shows a peak on channel "B" at 15 Hertz and a flat line across the frequency spectrum on channel "A".



Questions:

1. ·· How do you know if the peak at 15 Hertz is a natural frequency or an ambient vibration from adjacent machinery?

Answer

You don't know if the peak is a natural frequency. It may be an existing background vibration.

2. ·· What could be done to determine if the peak is an ambient vibration?

Answer

Take an ambient, non-triggered spectrum of the "B" channel signal and see if the peak is present.

3. ·· Why is the spectrum of channel "A" a line across the entire frequency span?

Answer

*That **is** the spectrum of the hammer hit (low level, broad-band energy) assuming that the hammer has the appropriate tip hardness to provide the required frequency.*

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4. ·· Why is the line flat?

Answer

The line is flat because the hammer tip hardness was sufficient to input energy into the structure out beyond 200 Hertz. If a softer tip was used, the line would have drooped towards zero at the higher frequencies.

The Monitor Spectrum mode does not display waveforms or allow for data storage. Any important information in data measured using Monitor Spectrum must be written down before the analyzer display is changed. A better way to measure dual channel impact data is to use the ACQUIRE SPECTRUM function.

Dual Channel Impact Testing in the Acquire Spectrum Mode

The analyzer setup for dual channel impact testing using the **Analyze/Acquire Spectrum** mode is shown below. The units for channel "A" must be sensor. The units for channel "B" can be acceleration, velocity or displacement. Uniform windowing should be used when measuring impact data. Keep the lines of resolution at 200 or 400. High lines of resolution are not necessary for impact testing.

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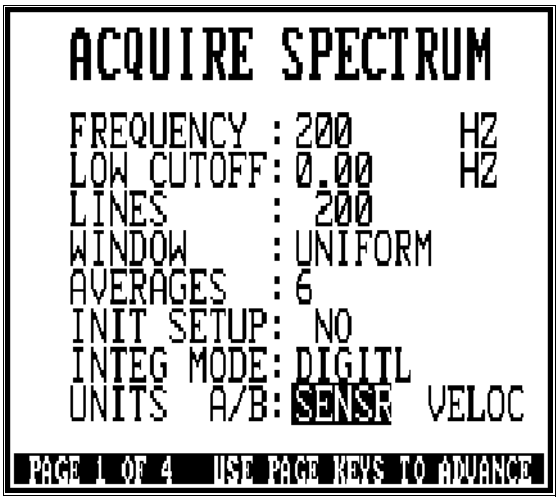
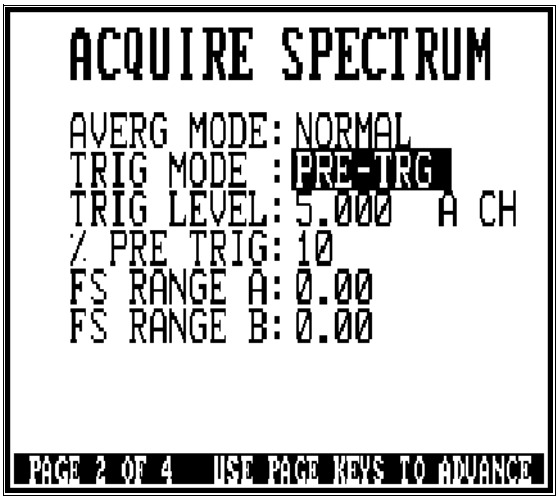
Unlike the Monitor Spectrum mode, the number of averages can be set in the Acquire Spectrum mode. The measurement ends after the averages have been completed. Use between 3-6 averages for impact testing. Set-up the remainder of the screens as shown and begin the impact test. The Pre-Trigger function is explained in the next section.




ACQUIRE SPECTRUM
AVERG MODE: NORMAL
TRIG MODE : PRE-TRG
TRIG LEVEL: 5.000 A CH
% PRE TRIG: 10
FS RANGE A: 0.00
FS RANGE B: 0.00
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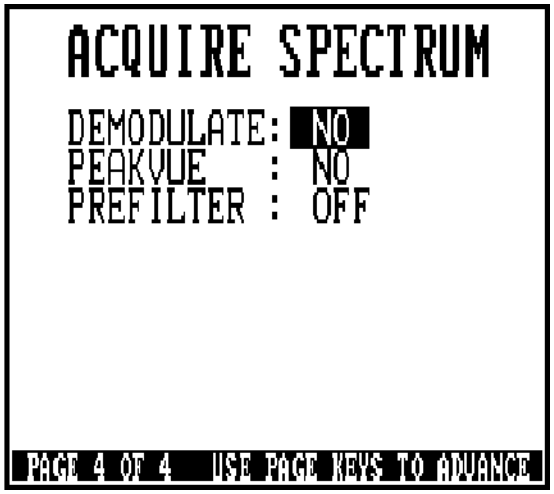
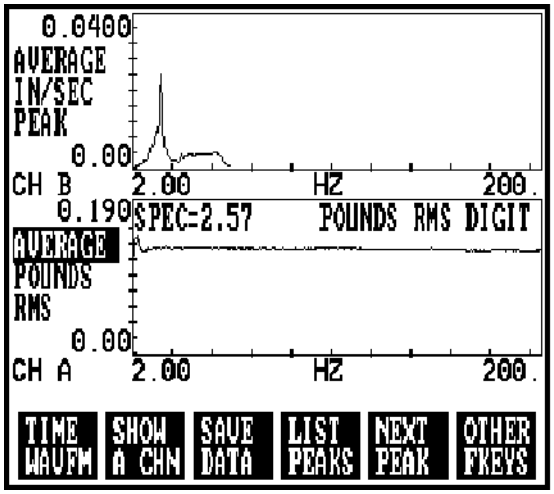
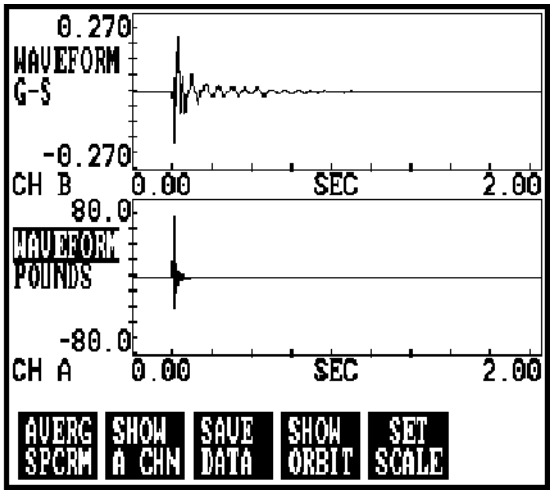


When the measurement is finished, the averaged spectrums of channels "A" and "B" are displayed. The F1 key toggles the display to show the time waveforms for the two channels. Notice the difference between the two waveforms. Channel A, the hammer, is a sharp spike ñ representative of a single impact. The spectrum of the impact contains low energy over a broad frequency span – as shown in the spectrum of channel A.

The Channel "B" Waveform shows an impact and a ring down. A natural frequency in the structure was caused to resonate by the hammer impact. The spectrum of channel "B" shows the resonant frequency.





The F3 key allows the data to be stored to the existing route. The point that is currently active on the analyzer will receive the data. Another way to store the data is to press ANALYZE then STORE DATA.

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Note

If no routes are currently active on the analyzer, the F3 key will not be shown and data cannot be saved.

2. Dual Channel Impact testing using the Advanced 2-Channel DLP

The Advanced Two-channel DLP is optional firmware for the 2120-2 analyzer. It provides additional cross-channel capability to the analyzer and allows all data to be saved to analyzer memory. The Advanced Two-channel DLP is not necessary for impact testing, however is a required component for Modal Analysis.

The Advanced Two-channel program (if available on the analyzer) is selected by pressing the PROGRAM SELECT button at the top of the analyzer. Place the cursor over the program and press enter.

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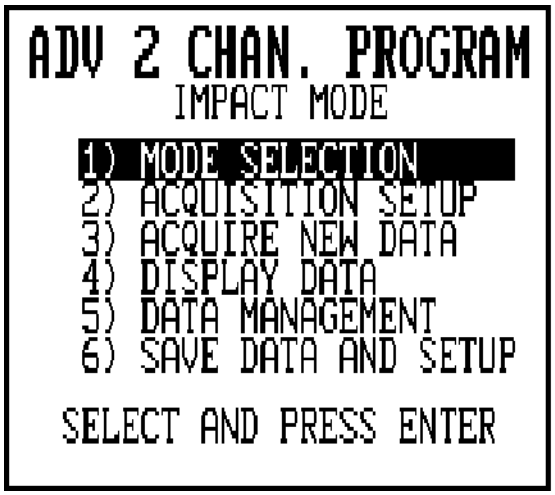
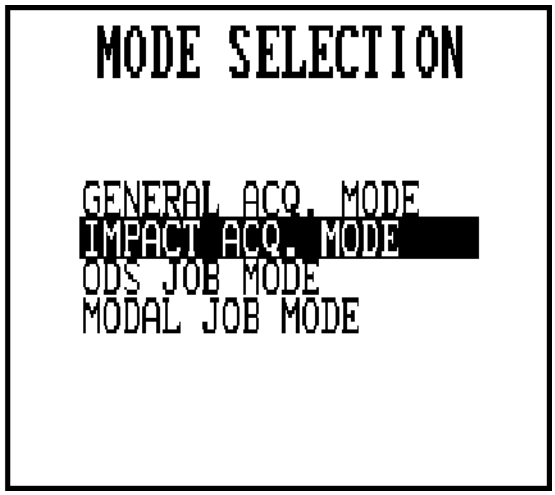
The program has four operational modes selected by pressing the MODE SELECTION key on the main menu. The **General Acquisition Mode** is used to make phase, coherence or transfer function measurements. The **Modal** and ODS modes are customized menus for doing those jobs and the **Impact Acquisition Mode** is used for dual channel impact testing.

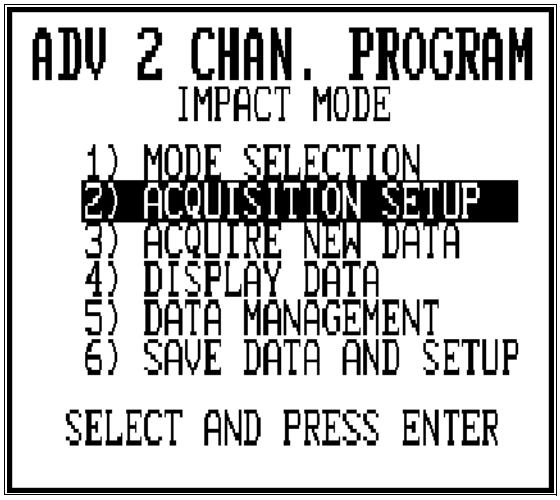




Choose the Impact Acquisition Mode for impact testing.

The Impact Mode main menu contains selections for configuring the measurement, acquiring data and saving both the measurement set-up and data.

Choose the Acquisition Set-up menu item then Acquisition Parameters.



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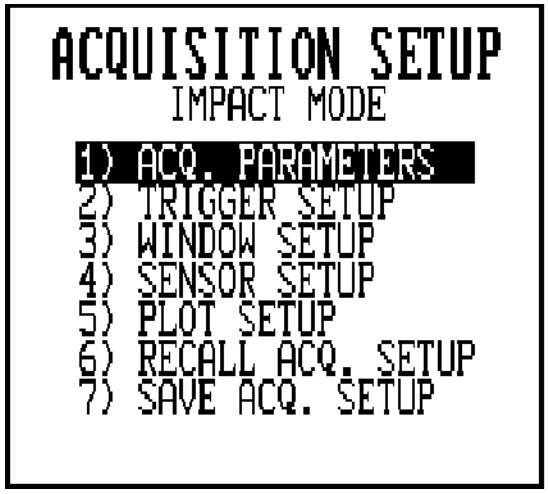
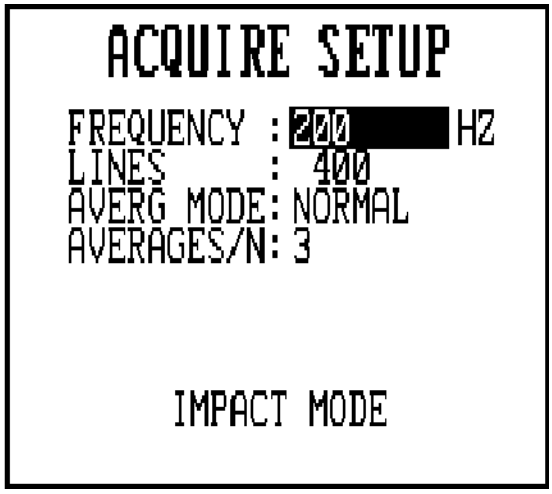
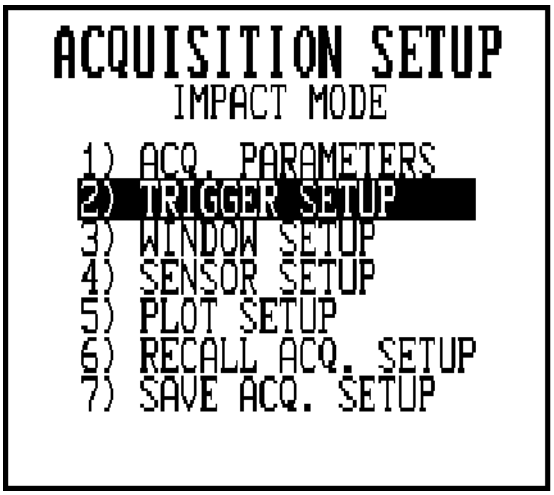
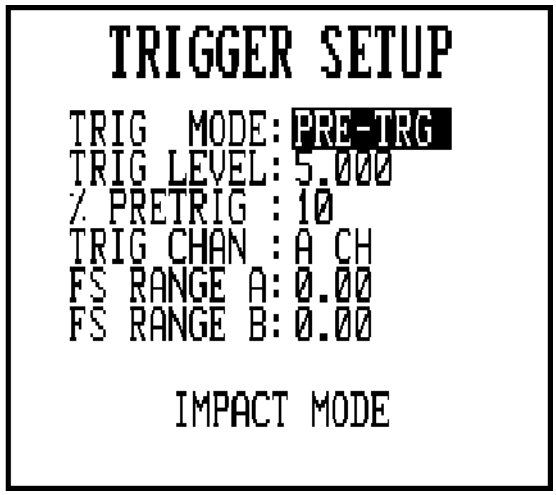
Acquisition Parameters: Configure the Acquire set-up for the F_{max}, lines of resolution and number of averages needed. Keep the F_{max} low enough to see the frequencies of interest and don't use high lines of resolution unless its needed. Press enter and select the Trigger Set-up menu.





Trigger Setup: The PRE-TRIGGER method is the best trigger mode to use for impact testing because it offsets the impact from the left edge of the time waveform and is easier to see. When the impact is at T=Zero seconds, it is more difficult to see. When Pre-Trg is used, a percent pre trigger value must be specified. In the example above, 10% pre-trigger is specified. This means that when the analyzer is triggered, 10% of the time waveform length is displayed prior to the impact. The trigger is based on the signal from channel "A". A trigger level of 5 pounds is required before the trigger occurs.





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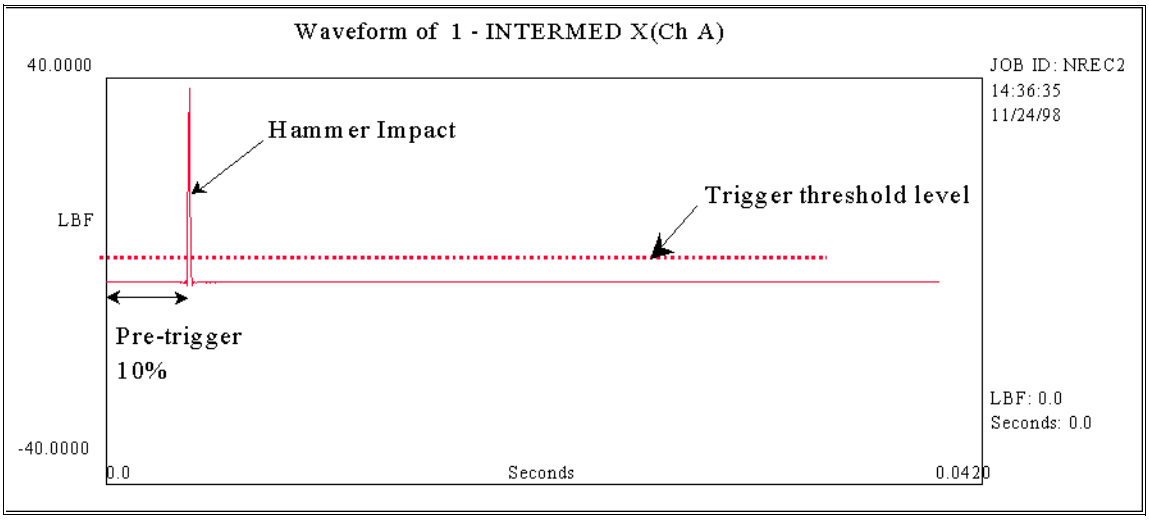
In the example impact plot shown below, the pre-trigger places the impact 10% away from the left edge of the time waveform. The dotted line represents the trigger threshold level. In this case, the impact was about 40 pounds force. The threshold was set at 5 pounds. A hammer hit of 5 pounds or more is required for the analyzer to trigger.



A FS Range of zero means that the analyzer auto-ranges the analyzer's input buffer for the incoming impact signal. Auto-ranging is recommended. It may take a few extra hits for the analyzer to select the proper range, however the data will always have good signal-to-noise ratio.

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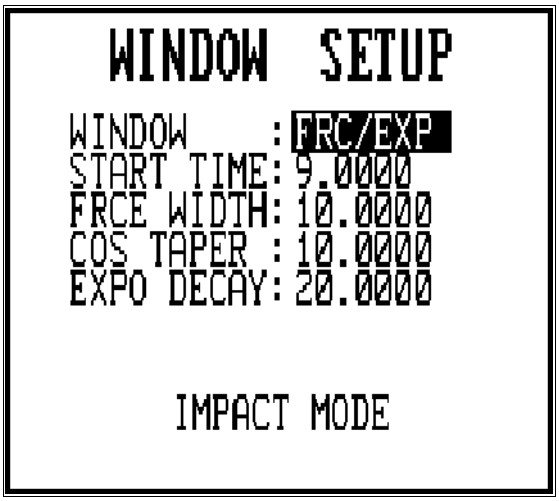
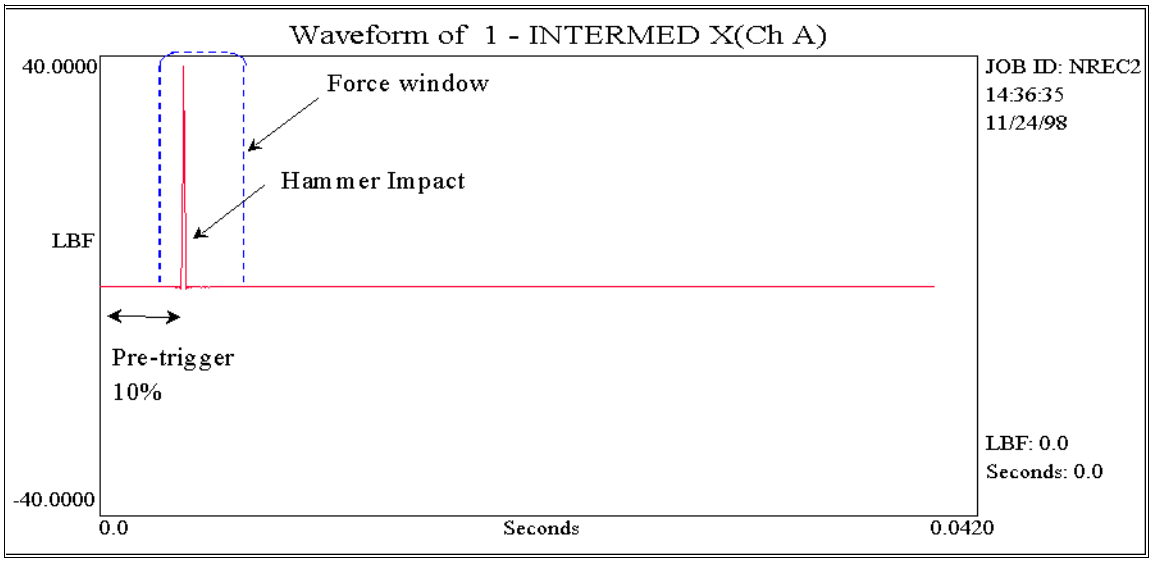
Window Setup: Window functions shape the time waveform data. The Advanced 2-channel DLP has a Force/Exponential Window function for impact testing. This window function is only available in the Advanced 2-channel DLP.



The Force/Exponential window function is actually two separate window functions. The Force window function is applied to the hammer channel time waveform. It is a rectangular window applied around the impact. It's purpose is to reduce signal other than the impact.



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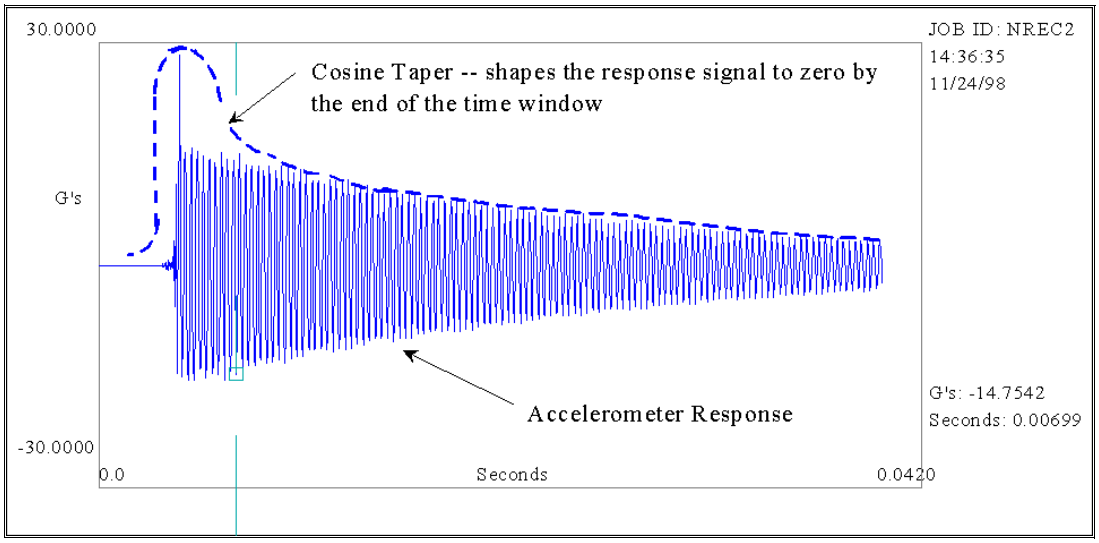
The Exponential Window is applied to the response accelerometer time waveform. Its purpose is to reduce the ring-down to near zero amplitude by the end of the time waveform. The Force/Exponential Window set-up settings can be changed, however the defaults usually work well. The settings are explained below.



Waveform of 1 - Intermed X (Ch B)

Window - The (**FRC/EXP**) - force/exponential window used for impact testing

Start Time - Specifies the start position of the data in the window as a percentage of the total window. The default setting is 9% and assumes that the pre-trigger setting is 10% (in the Trigger Set-up). The start time must always be lower than the pre-trigger setting

Force Width - Specifies the width of the force window in percent of the total waveform. The default is 10%

Cosine Taper - Defines the time for the cosine taper at the beginning and end of the force window. It is entered as a percentage of the window width. The default is 10%

Exponential Decay - Defines the decay constant for the end of the exponential window and is entered as a percentage of the total waveform. The default is 20%

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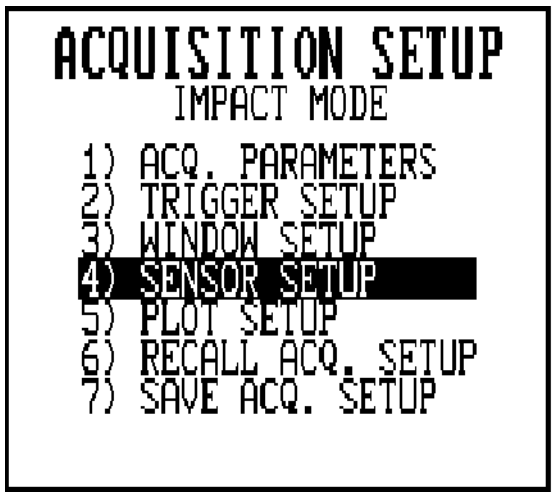
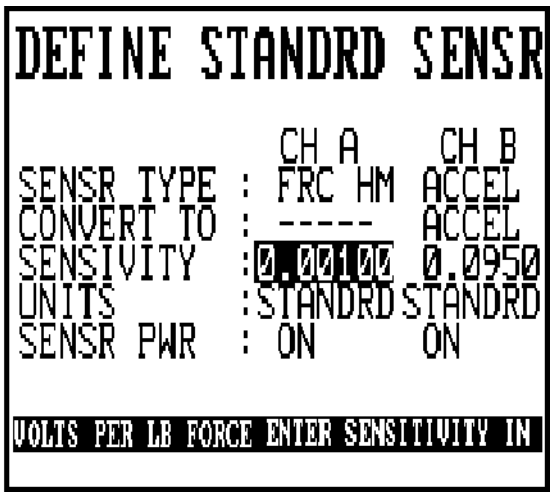
Sensor Setup: Select the SENSOR SET-UP screen from the Acquisition Set-up menu.

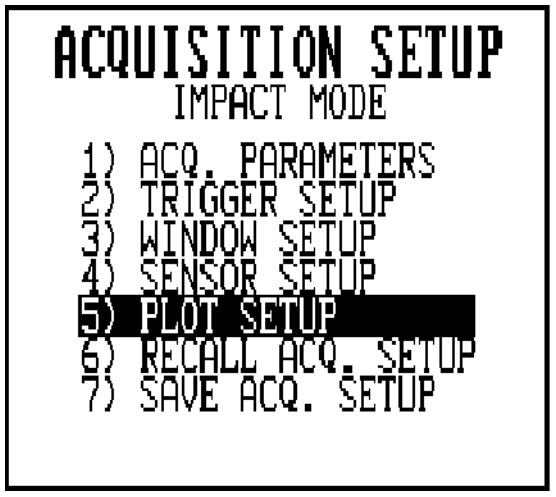


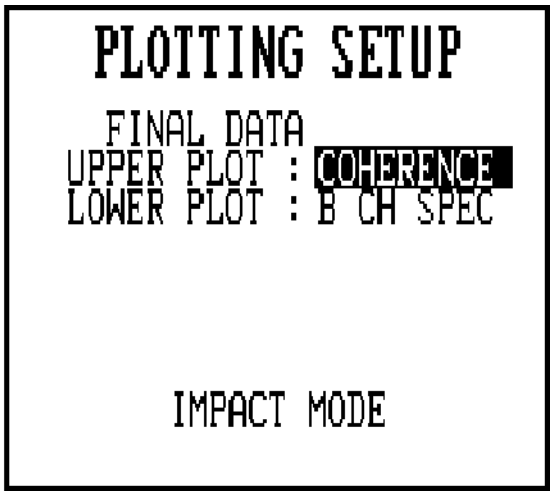

DEFINE STANDRD SENSR
CH A CH B
SENSR TYPE : FRC HM ACCEL
CONVERT TO : ----- ACCEL
SENSIVITY : 0.00100 0.0950
UNITS : STANDRD STANDRD
SENSR PWR : ON ON
VOLTS PER LB FORCE ENTER SENSITIVITY IN

In the Advanced Two-channel program, a FRC HM (force hammer) sensor is available as one of the sensor choices. In case you forget the hammer sensitivity, placing the cursor on the SENSITIVITY field and pressing the HELP key displays a list of impact hammer model numbers and the corresponding sensitivity in volts per pound and volts per Newton.

An accelerometer is used as the "B" channel sensor. The CONVERT TO can be set to acceleration, velocity or displacement.

Plot Setup: The next menu item is PLOT SET-UP. This screen sets the desired final plots once the impact data has been acquired. The recommended settings are Coherence and "B" channel spectrum.





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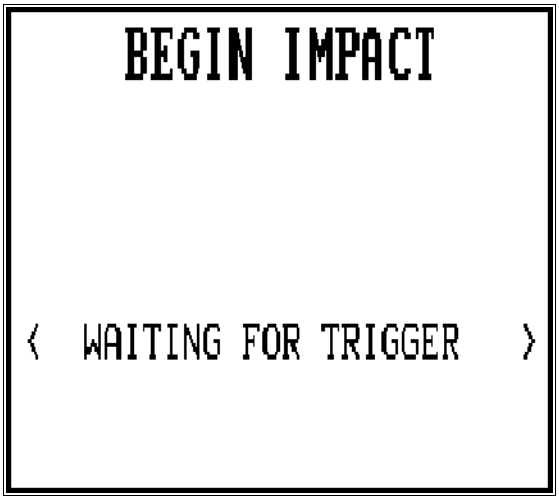
Press RESET to return to the Advanced 2-channel Main Menu. Select Acquire New Data to begin the test. The analyzer will display message prompts to strike with the force hammer as it attempts to range the input buffer. After ranging, the message will change to BEGIN IMPACT ñ WAITING FOR TRIGGER.



After acquiring the first average, the impact waveform is displayed. The F1 and F3 keys are available to either accept or reject the average. Look at the impact. If it is a clean impact with no double hits, press F1 to accept ñ otherwise reject the data and impact again.

Once accepted, the display changes to show the impact waveform of channel "A" and the coherence.

Why is the data is completely coherent for the first average?

Answer*: Coherence is an averaged function. All data is coherent after the first average. Coherence values will drop (slightly) at certain frequencies after the second, third, etc. impact. Since the input force is from a hammer that is providing low level, broad band energy across the spectrum, the coherence should not drop below 90 percent*.

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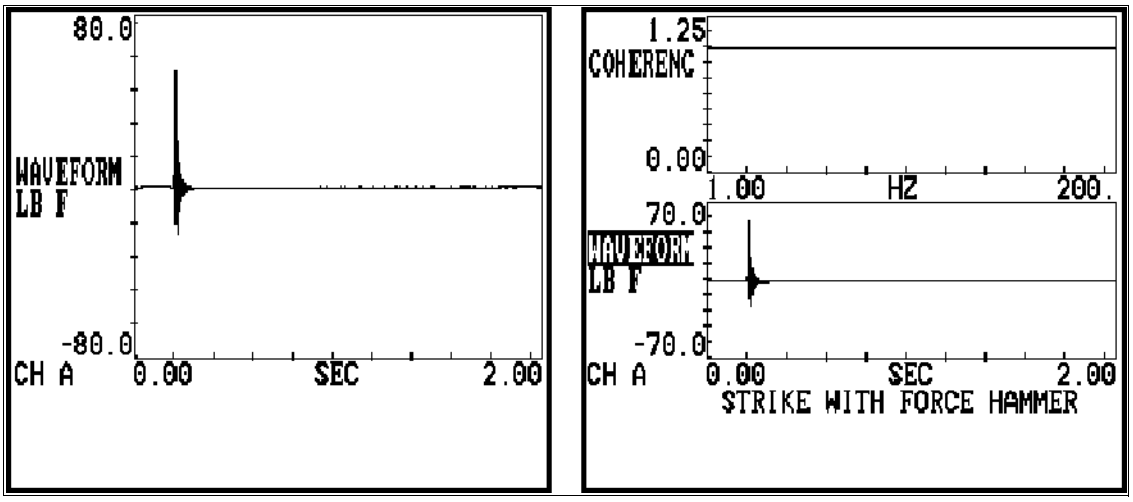
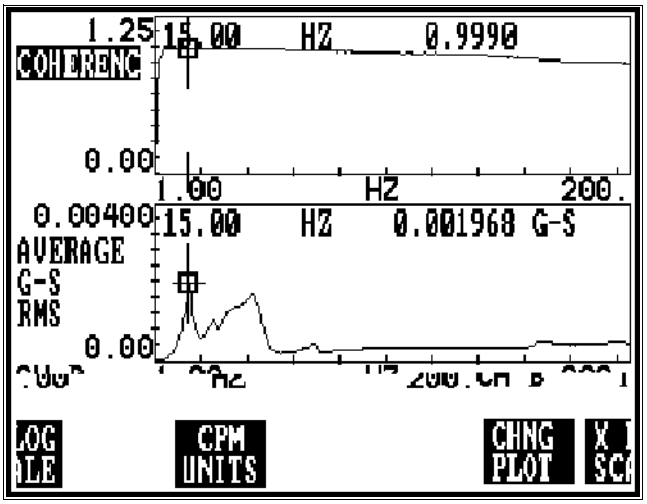


The message at the bottom of the dual plot is calling for another impact. Follow the analyzer prompts and complete the averaging. If the force of the impact increases or decreases significantly during the remainder of the averages, the analyzer will change range and ask for more practice hits.

After the averages have been completed, the plot display shows the Coherence and the averaged spectrum of channel "B". Coherence is used to verify resonance. If a peak in the spectrum has a coherence above 90% it means that the peak is a result of the impact rather than a background vibration. A low coherence value means that the spectral energy at that frequency is unrelated to the hammer hit and is probably background vibration.

The Page-Up or Page-Down keys switch cursor control between the upper and lower plots.



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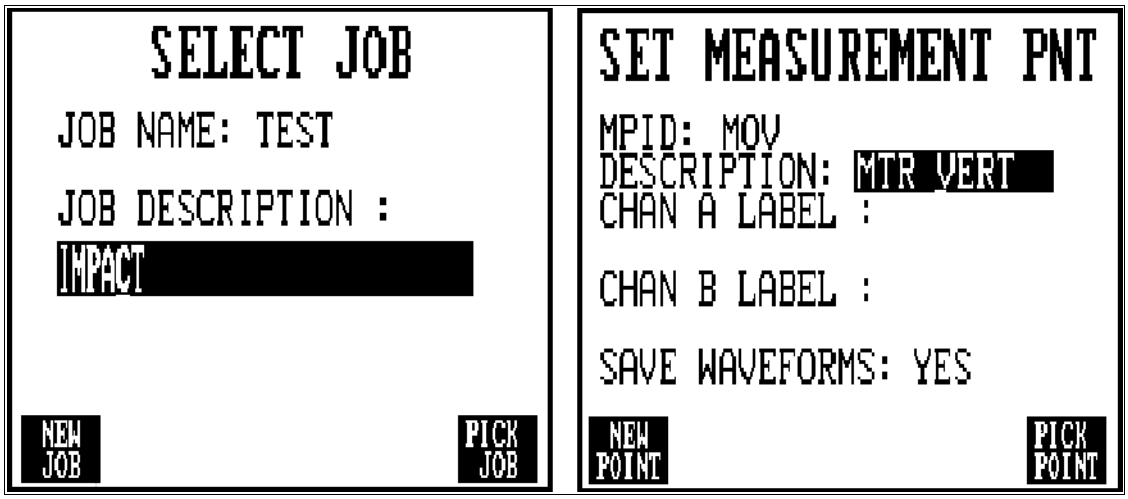
Saving Data: To save the data, press ENTER or RESET to return to the main menu. Select SAVE DATA and SETUP. Enter a job name (8 characters maximum). The job description field is optional.



Press Enter to save the data.

> ***Note***
> *If several impact tests are to be made, the MODAL mode provides an easier method of saving data that requires less keyboard typing.*

Data collected and saved using the Advanced 2-channel DLP is transferred to a host computer using VibPro Software. VibPro is a CSI software program used for Advanced Two-channel and Advanced Transient Data. VibPro software is covered in the second part of section six in this manual.

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Hammer Considerations for Impact testing

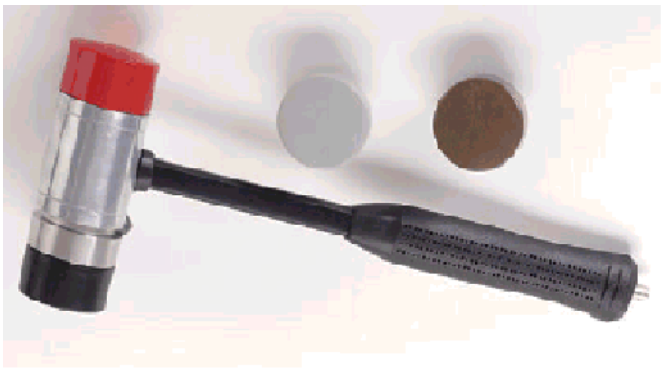
Force level and frequency content are important considerations when choosing a hammer. An improperly sized impact hammer results in missed natural frequencies. The hammer must deliver enough force to excite the natural frequencies (*to measurable amounts*). For example, when you test the springs in your car do you tap the bumper with a steel hammer? Of course not... you stomp on the bumper with your foot forcing the springs to bounce up and down. Would a steel hammer provide the frequency and force necessary to excite the car's springs? Sure it would, but not to observable amounts.

Impact hammers come in various sizes such as the one pound, three pound and a twelve pound sledge models.

One Pound Hammer: This hammer has the capability to deliver 500 lbf with a 8,000 Hertz frequency response and has a sensitivity of .01 v/lbf. Model A034701.

The hammer comes with a steel, nylon and a variety of softer plastic tips. Also included is a mass extender.

Three Pound Mini Sledge: This hammer has the capability to deliver 5000 lbf with a 1,000 Hertz frequency response and has a sensitivity of .001 v/lbf. Model A034703.



The hammer comes with four plastic tips.

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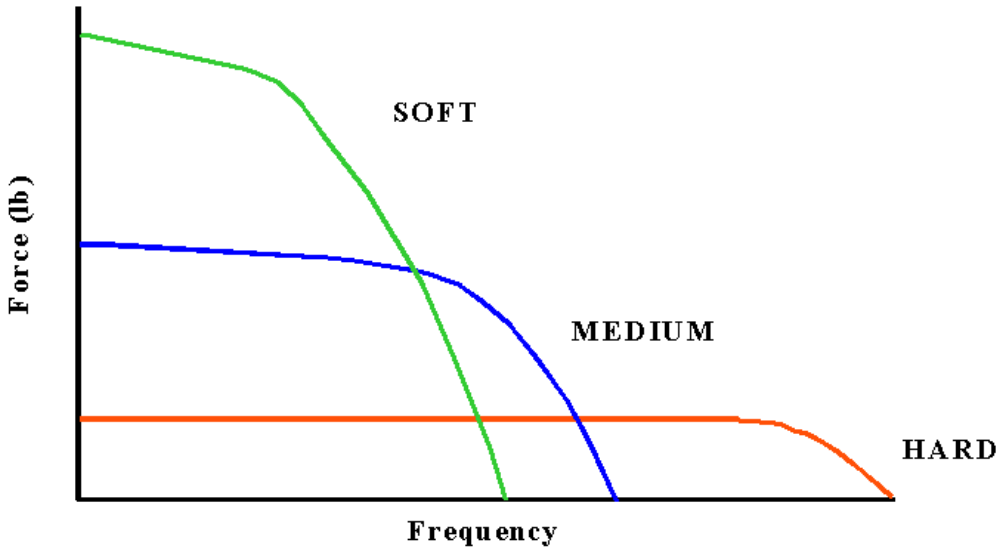
Twelve Pound Mini Sledge: This hammer has the capability to deliver 5000 lbf with a 500 Hertz frequency response and has a sensitivity of .001 v/lbf. Model A034712.

The hammer comes with four plastic tips.

The hammer mass determines the amount of force delivered and hammer tip hardness determines how much frequency is delivered.

The graph below demonstrates the relationship between hammer force and frequency. Softer tips deliver more force but less frequency. Harder tips deliver more frequency but less force.



Demonstration - Testing Hammer Tips

Follow the instructor's directions to test the frequency response of different hammer tips.

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Machinery Considerations

- Resonances is directional. Test the horizontal, vertical and axial directions separately for resonance.
- For best results, impact testing should be done with the machine off-line. Modal testing must be done with the machine off-line.
- As discussed earlier, natural frequencies may vary slightly between running and stopped equipment.
- Some machines are too massive to excite with a hammer and require alternative means of exciting the natural frequencies. On very large structures a dynamic shaker is used to input random, swept sign or other vibration patterns into the machine. Shakers can deliver a higher level of energy at each frequency into the machine.
- Determine the frequency range of interest before performing impact testing. Select an impact device with mass and tip hardness appropriate for the machine being tested.
- Before performing resonance testing it is very helpful to measure the background vibration levels -- especially for single channel impact testing. This can prevent mis-diagnosing a frequency in the background data as a resonance.

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Correcting Resonance Problems

Resonance problems often prove difficult to solve because of forcing functions present near the natural frequency. Resonance testing only identifies the natural frequencies of the machine. Modal analysis identifies the natural frequencies, mode shape and damping values.

Correcting resonance problems requires a thorough analysis of all modal data. Modal analysis alone does not offer a solution for the resonance problem. A Finite Element Analysis may be required. Natural frequencies cannot be eliminated ñ only shifted up or down the frequency range.

Some options for correcting resonance problems include:

1. ·· Move the forcing frequency away from the resonant frequency

2. ·· Reduce the exciting force (i.e. balance, align etc.)

3. ·· Change the mass or stiffness of the structure

4. ·· Add damping to reduce the amplification factor of the resonance

Options 3 and 4 generally involve some structural design changes that should not be made unless a modal analysis and/or a finite element analysis study has been performed on the structure.

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Review

In this section we have discussed natural frequency, resonance and critical. Several methods of testing for resonance were demonstrated including Single channel impact testing.

It is important to remember that all structures have natural frequencies (many of them). Natural frequencies are not a problem unless there are vibration frequencies present to excite them. If forced vibration excites a machine's natural frequency, amplification due to resonance will result. Natural frequencies cannot be eliminated - only shifted around in the spectrum through mass and stiffness changes.

Detecting resonance can often mean the difference between success and failure when troubleshooting machinery vibration problems. Resonance is very often the root cause of our high vibration problems.

Resonance testing only identifies the natural frequencies. Modal analysis identifies the natural frequencies, mode shapes and damping values. Modal analysis is required when it is necessary to identify the shape of component that is resonating. Modal analysis is the first step towards correcting resonance.

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Vibration Analysis Problems

Section 11

Objective

- Analyze six case histories using the knowledge gained in this course.

CSi means Reliability Training

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Introduction

In this section six vibration case histories are presented for analysis by the student. Spectral and waveform data is presented and other data is given as available. The final summary and problem analysis will be presented after this section.

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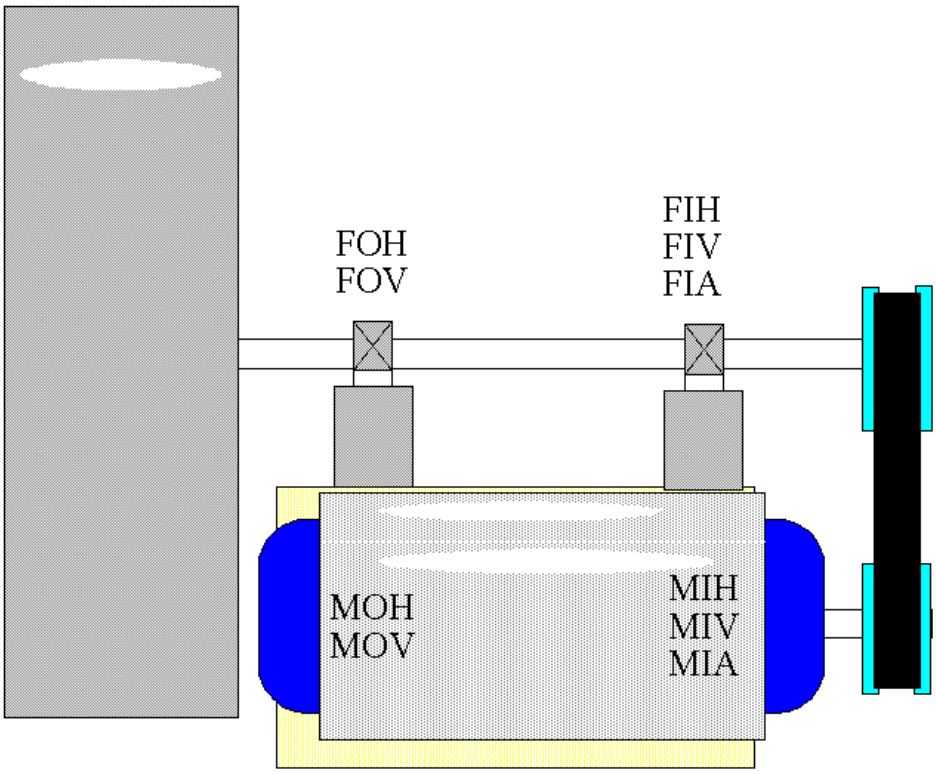
Case History #1 - Belt Driven Fan



Machinery information:

◆ 200 HP
◆ 1800 RPM belt-driven ovehung fan
◆ Motor sheave diameter 8.25”
◆ Fan sheave diameter 11”
◆ Center to Center 27.125”

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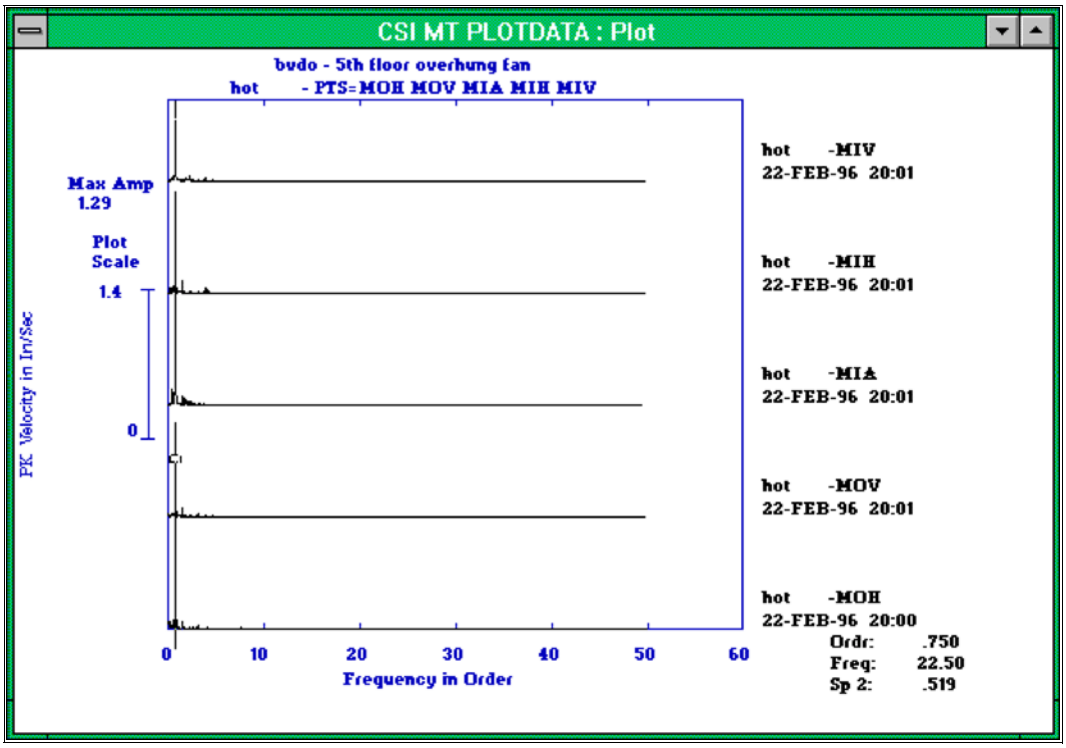

A multiple point plot is shown for the motor. A cursor marks the highest amplitude peak as measured on the motor. The individual spectrum for each motor point follows on the next pages.

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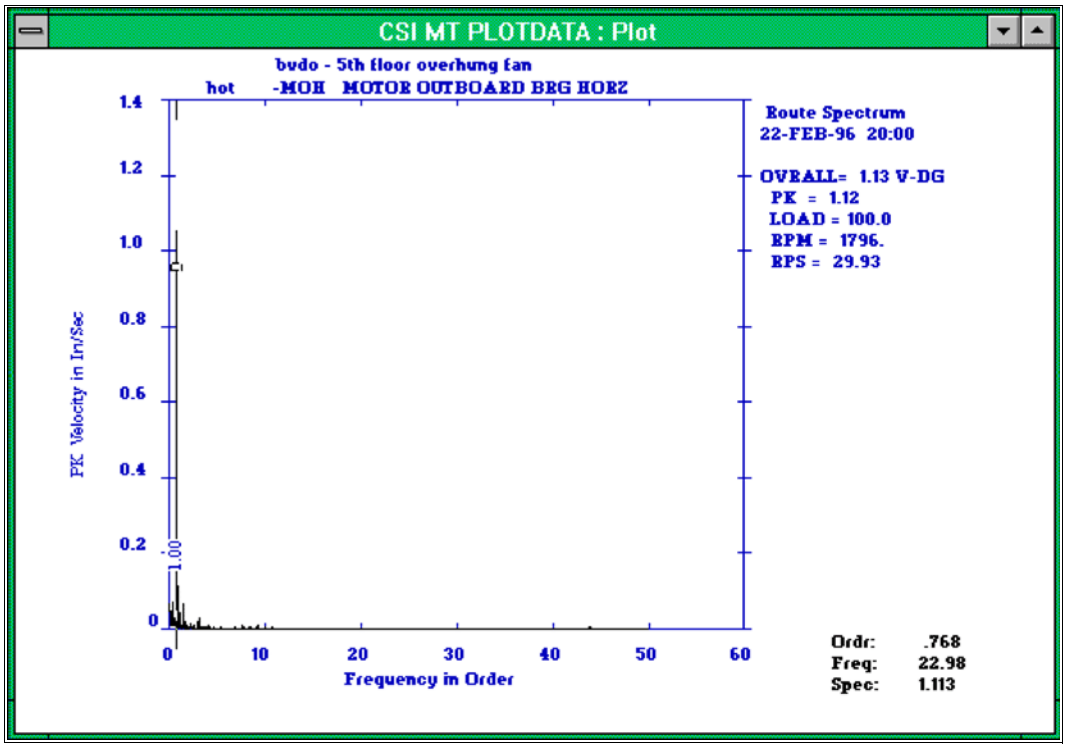

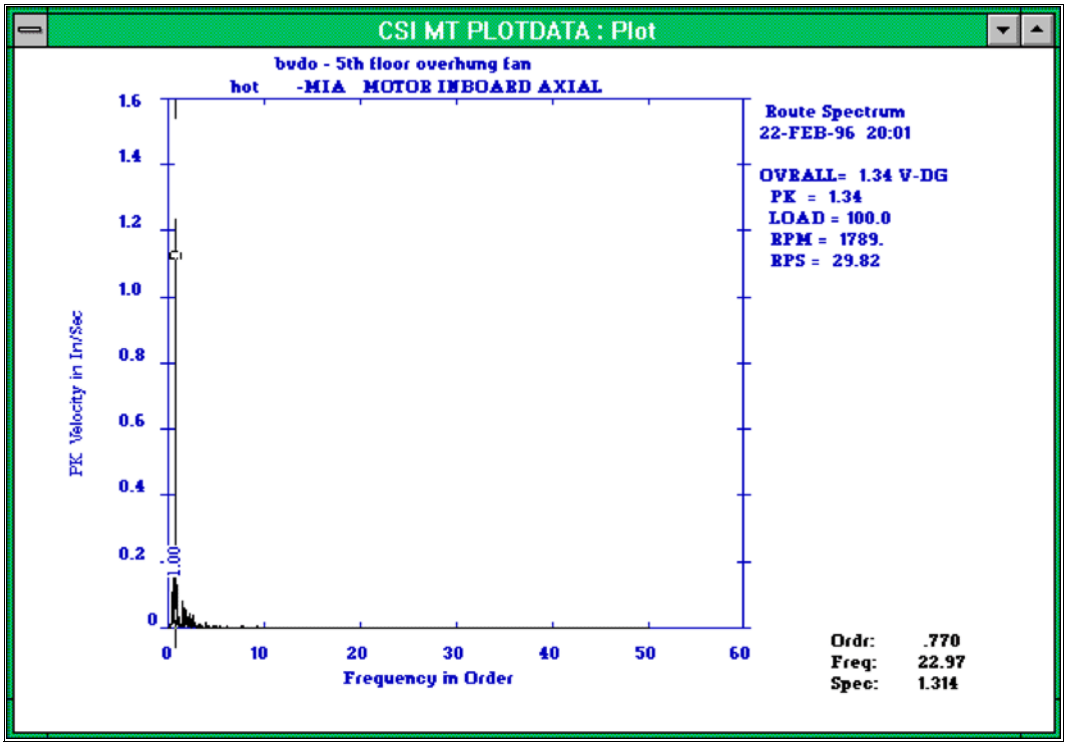

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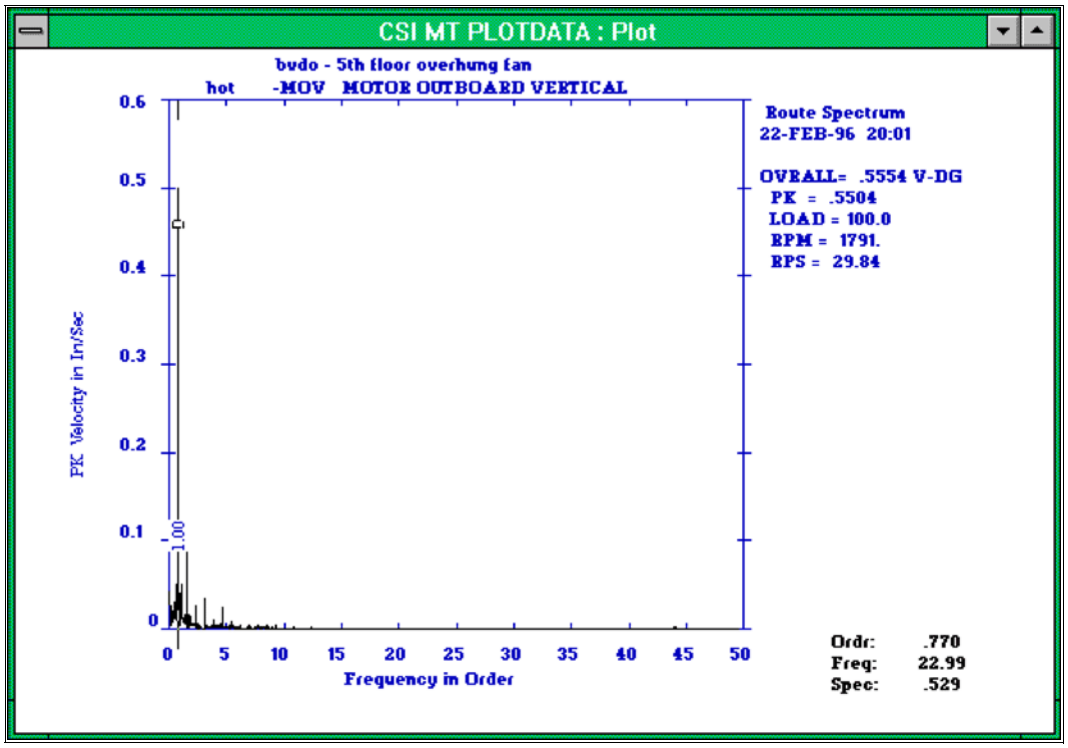

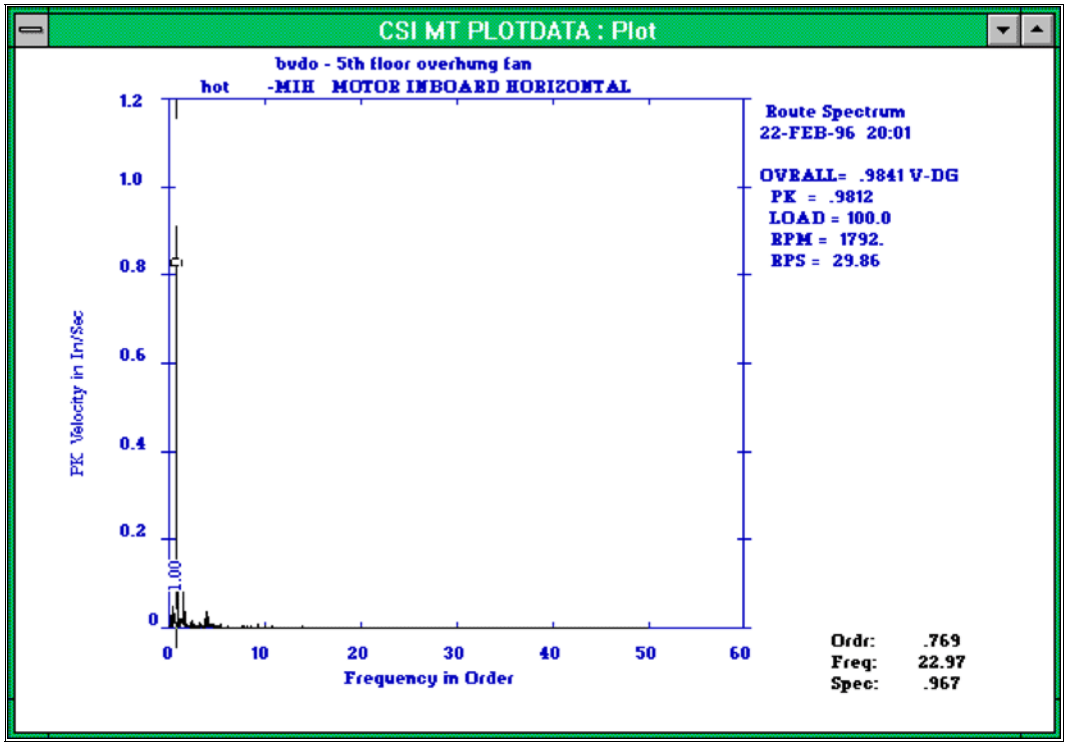

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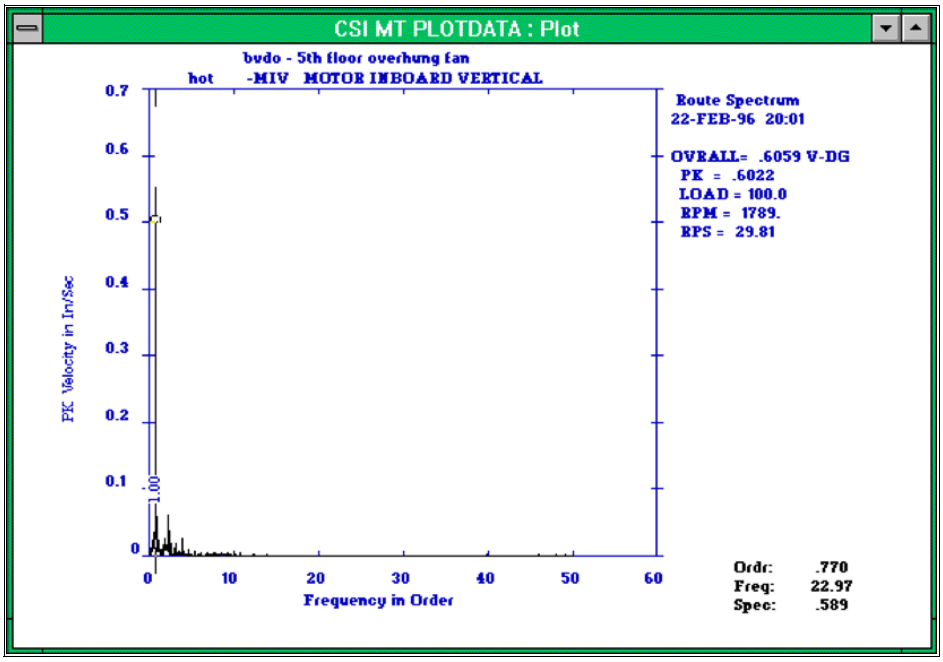
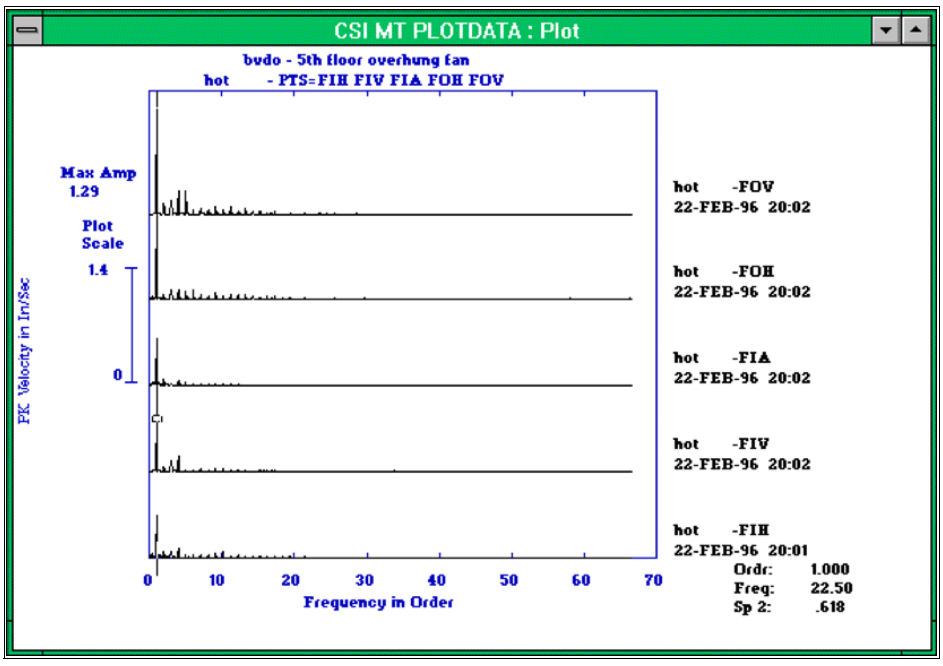


The motor data has been displayed, it now time to view the data on the fan. The next page shows a multiple point plot for the fan.



The multiple fan point data is shown above. The cursor marks the 1xTS of the fan at 22.5 Hz. Recall, this is the same peak that was marked on the motor's data. The single spectrum of each fan point is displayed on the following pages.

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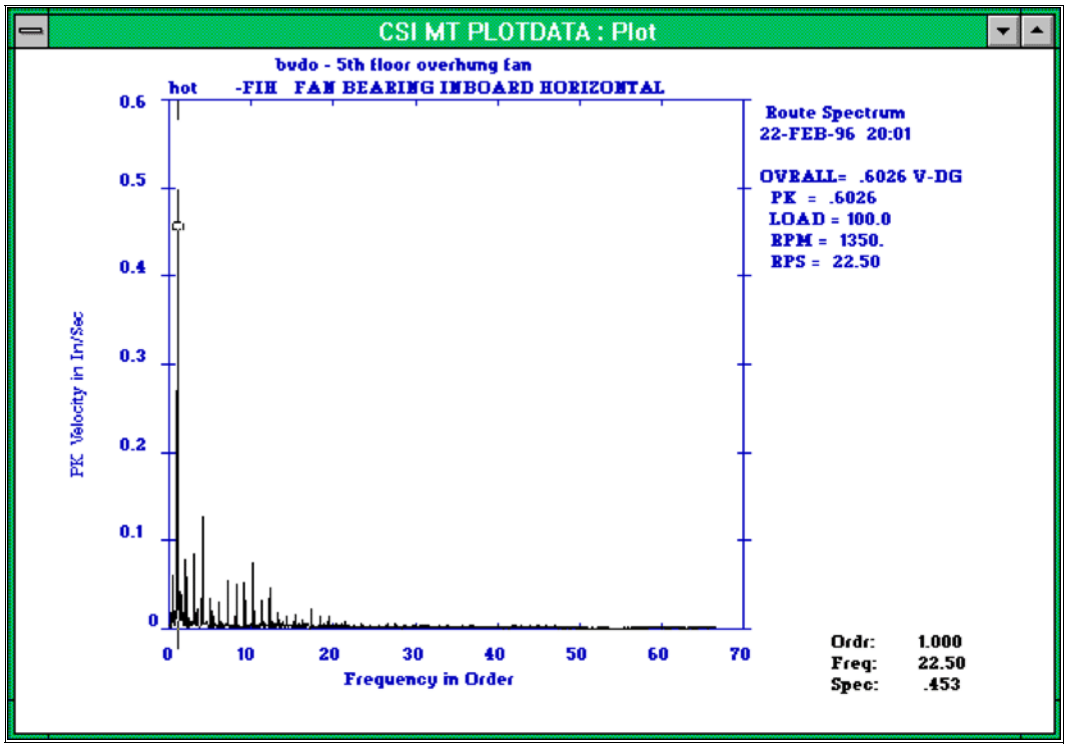

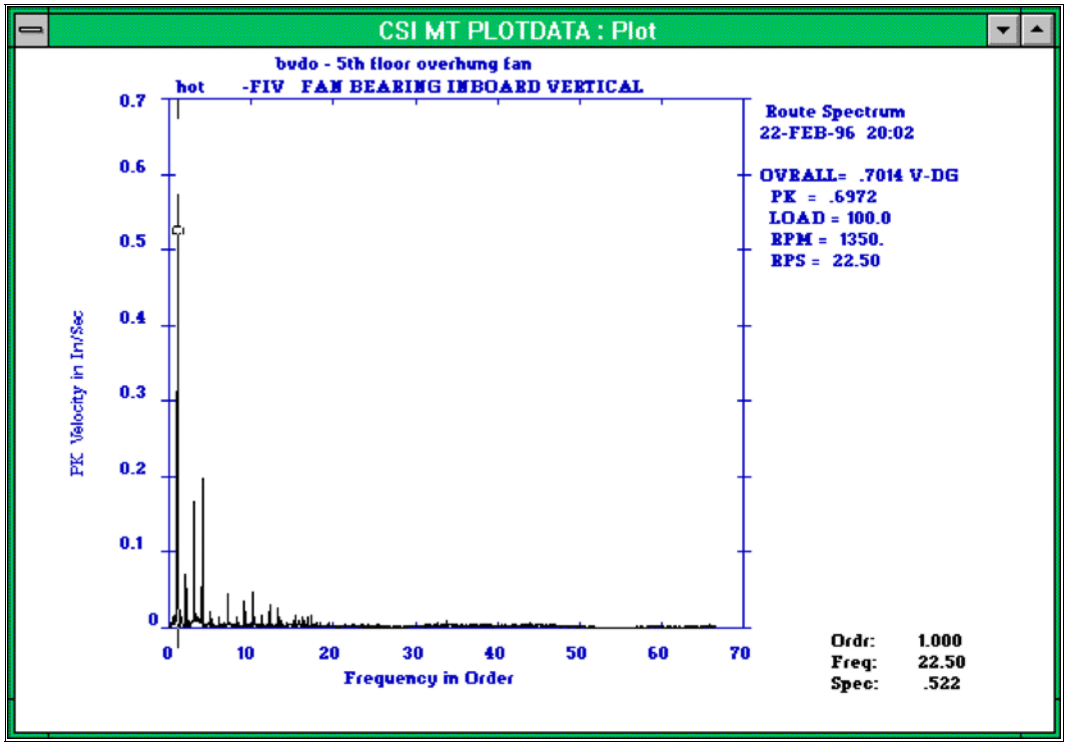

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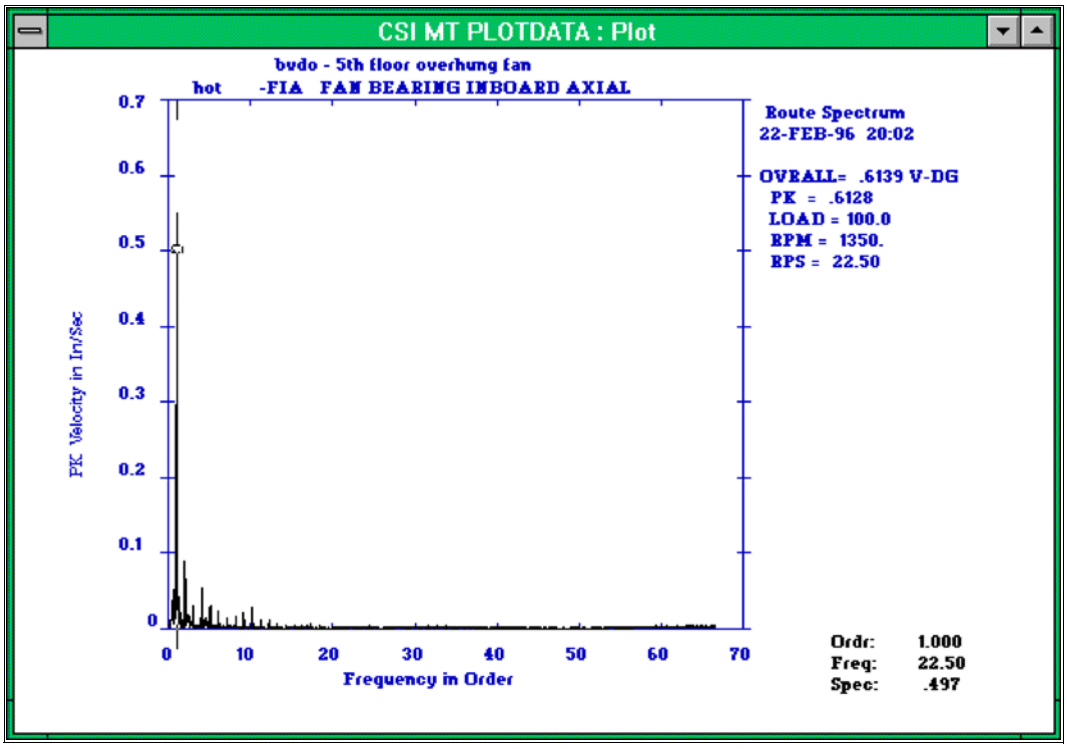

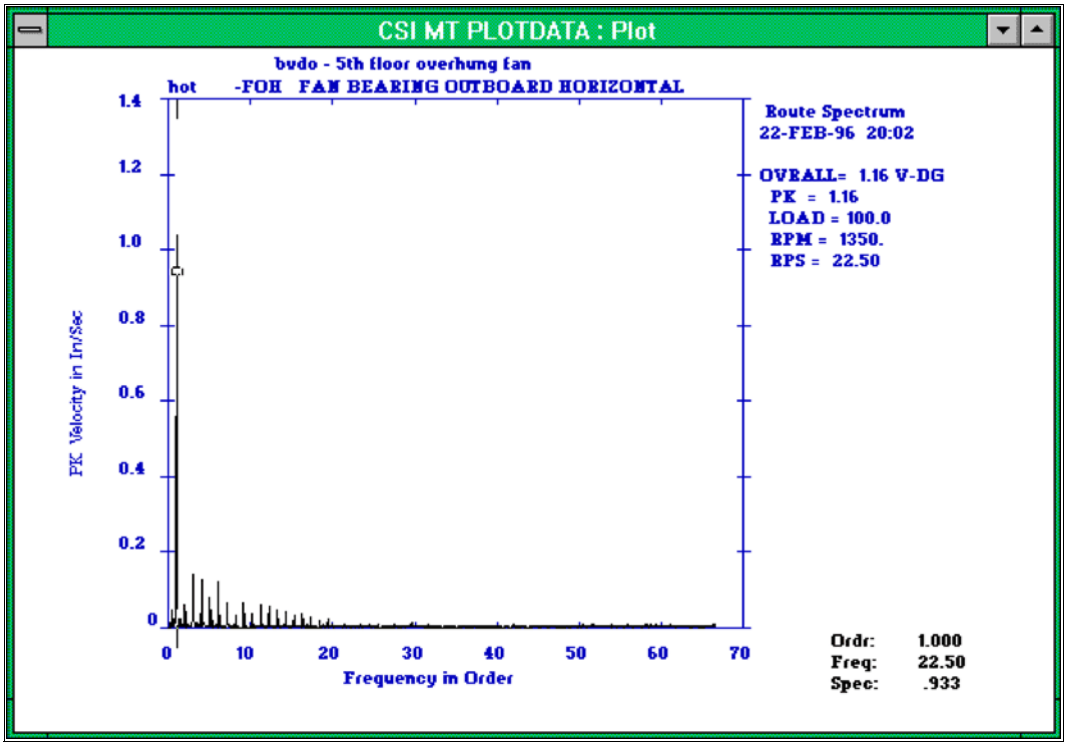

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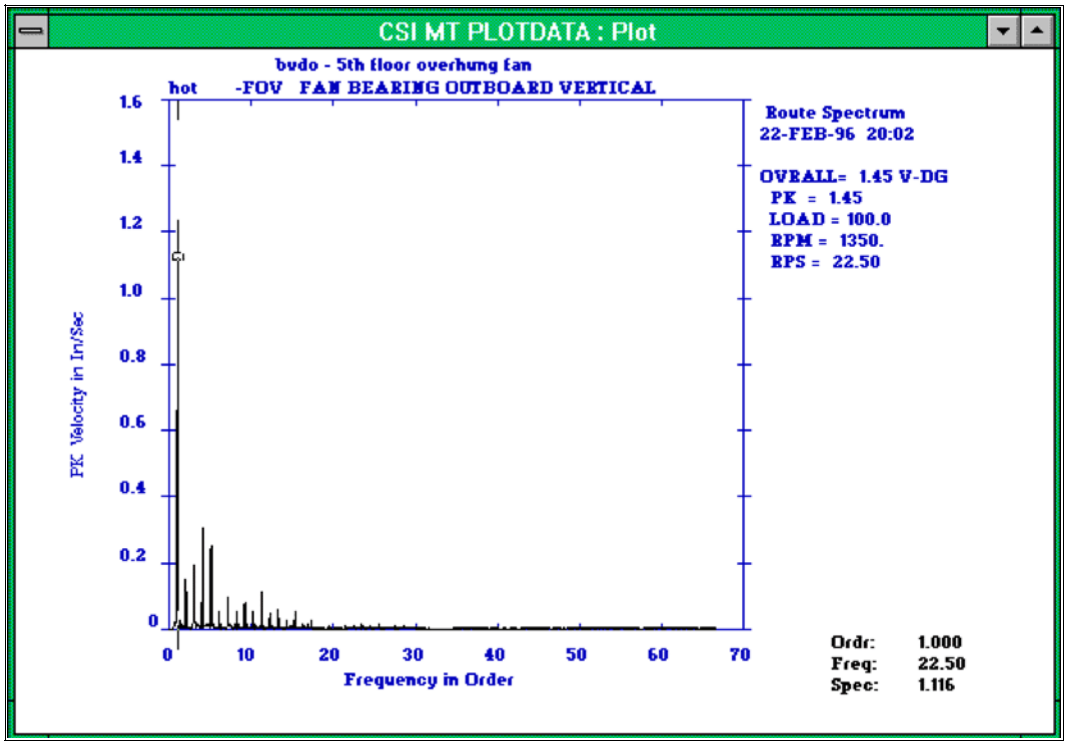

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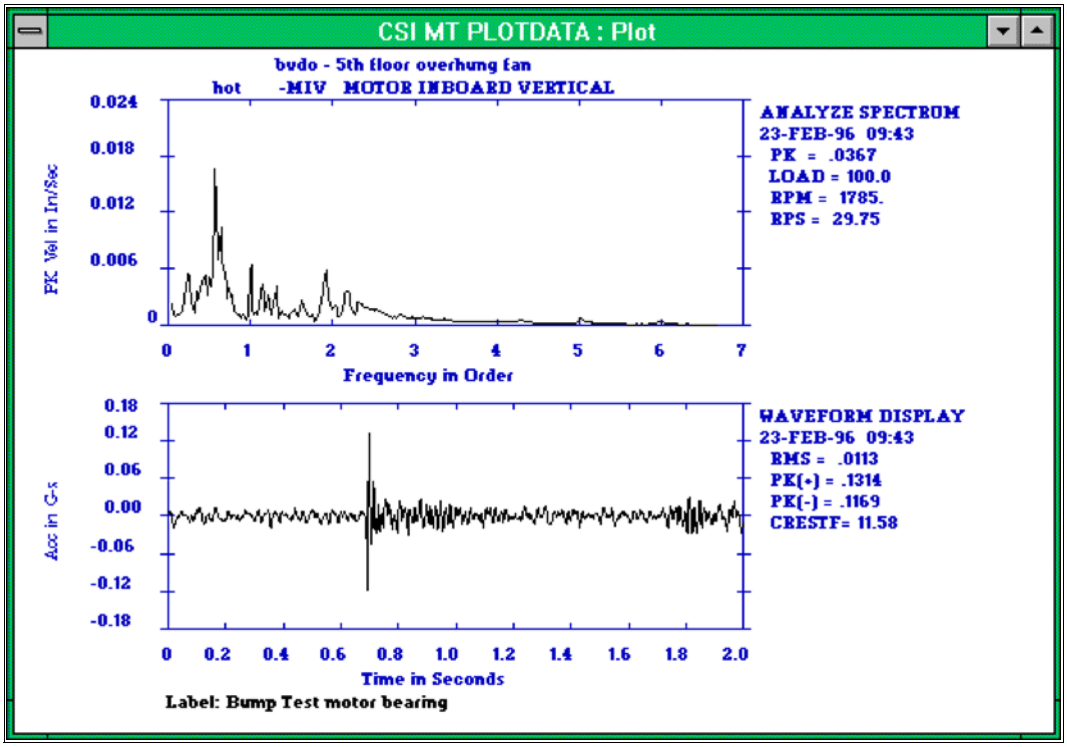
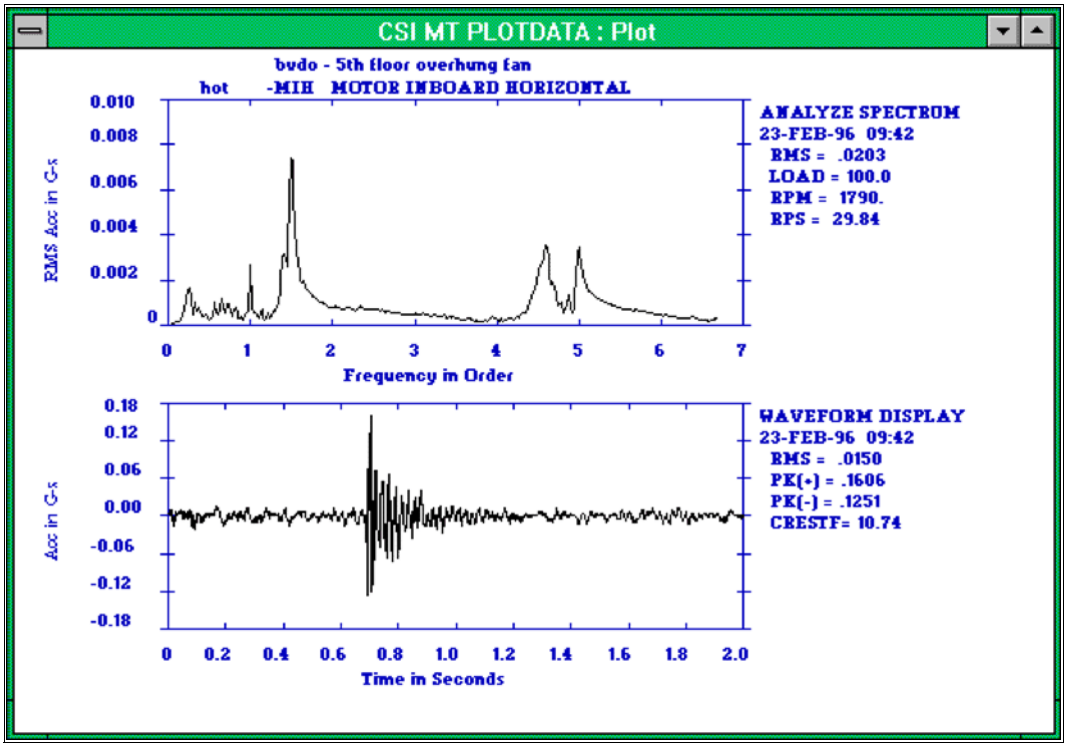
ADDITIONAL INFORMATION

CASE HISTORY #1 IMPACT TEST DATA





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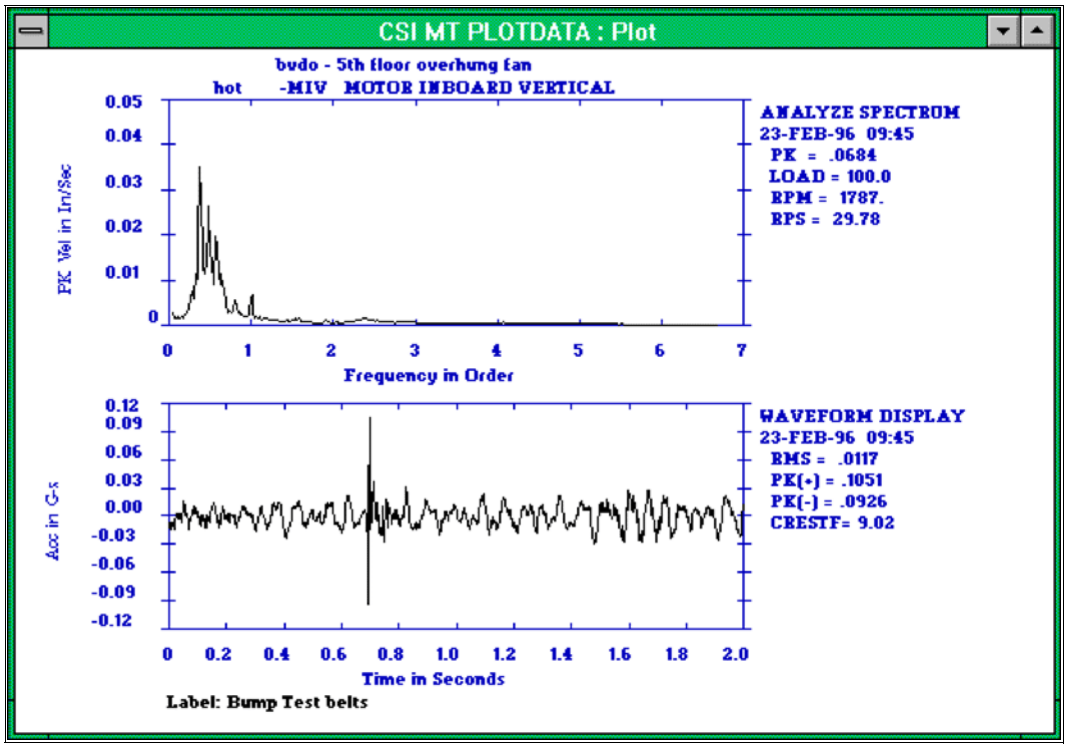

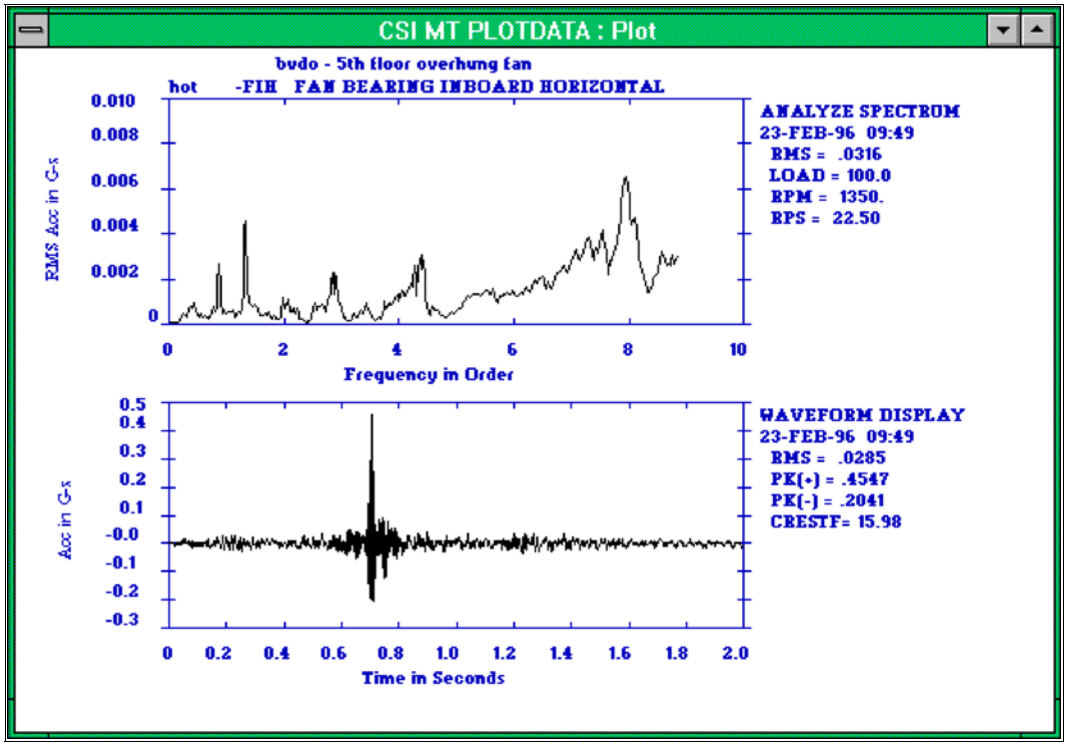

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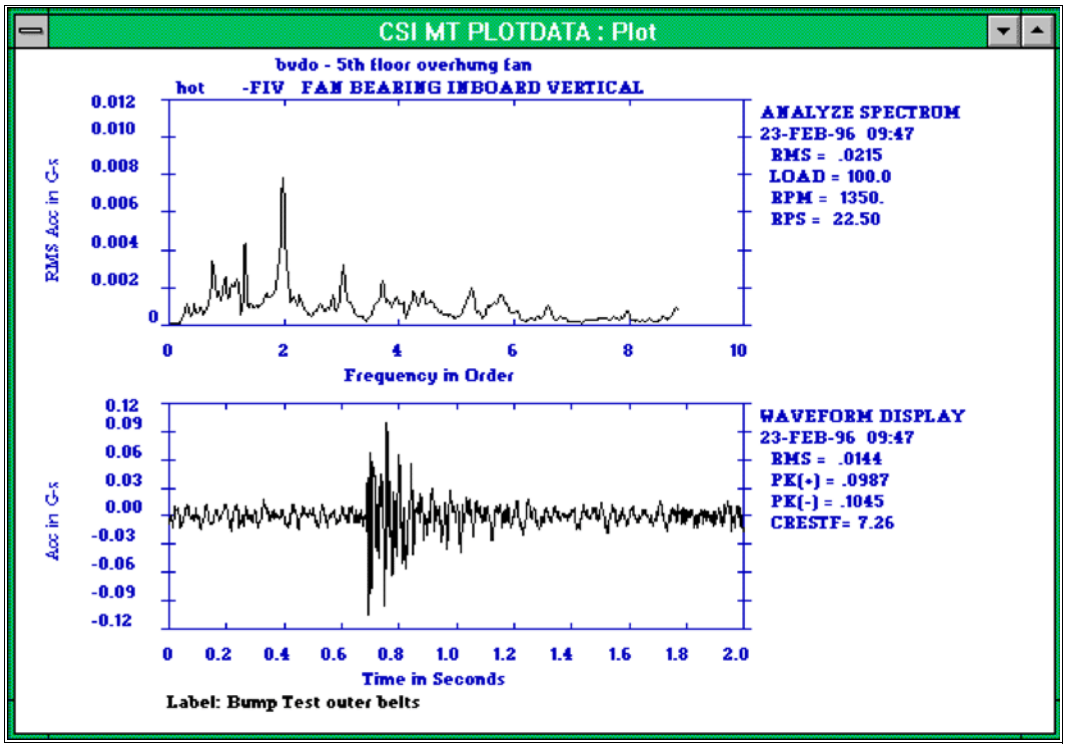

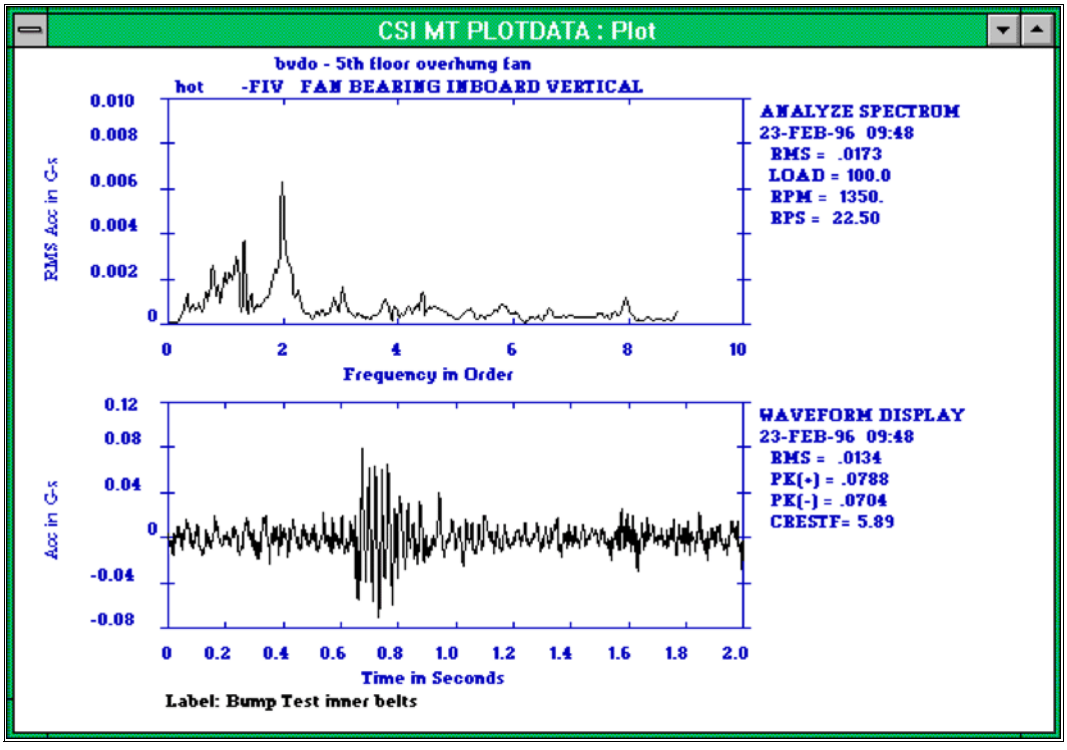

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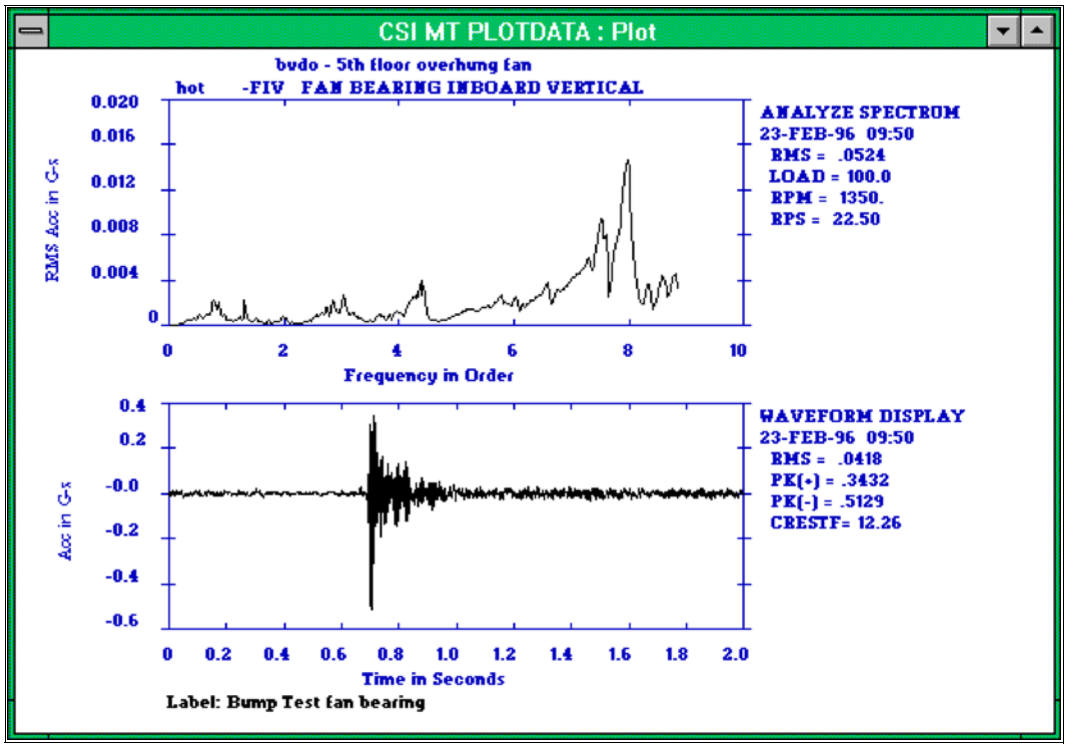

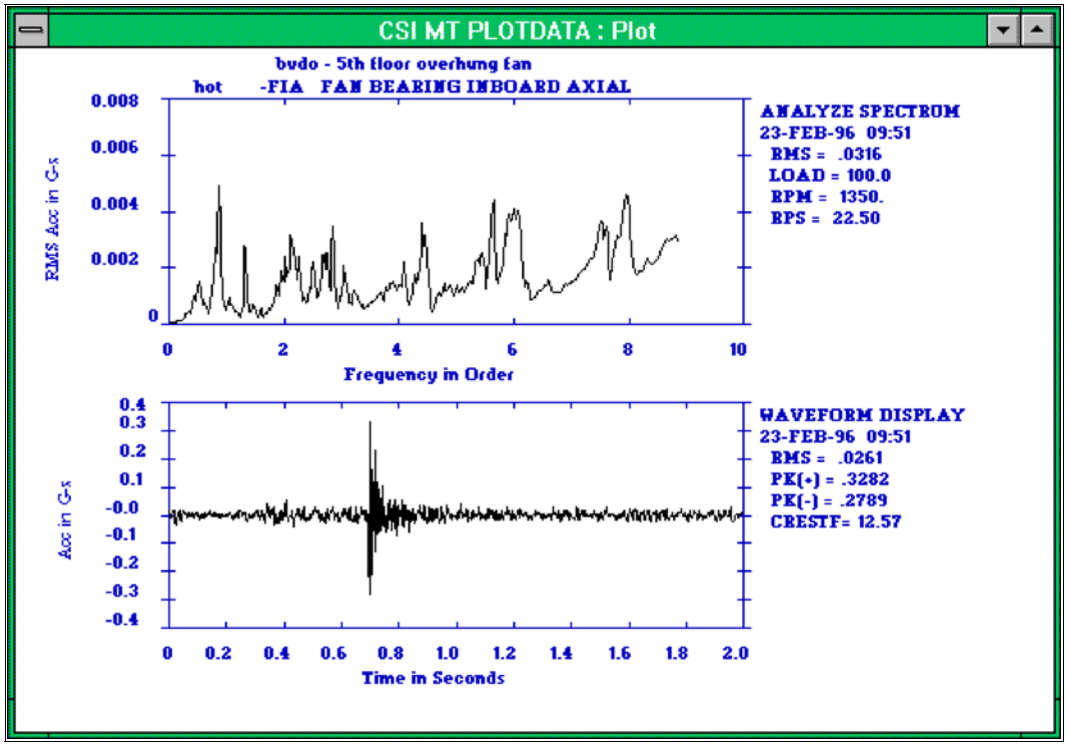

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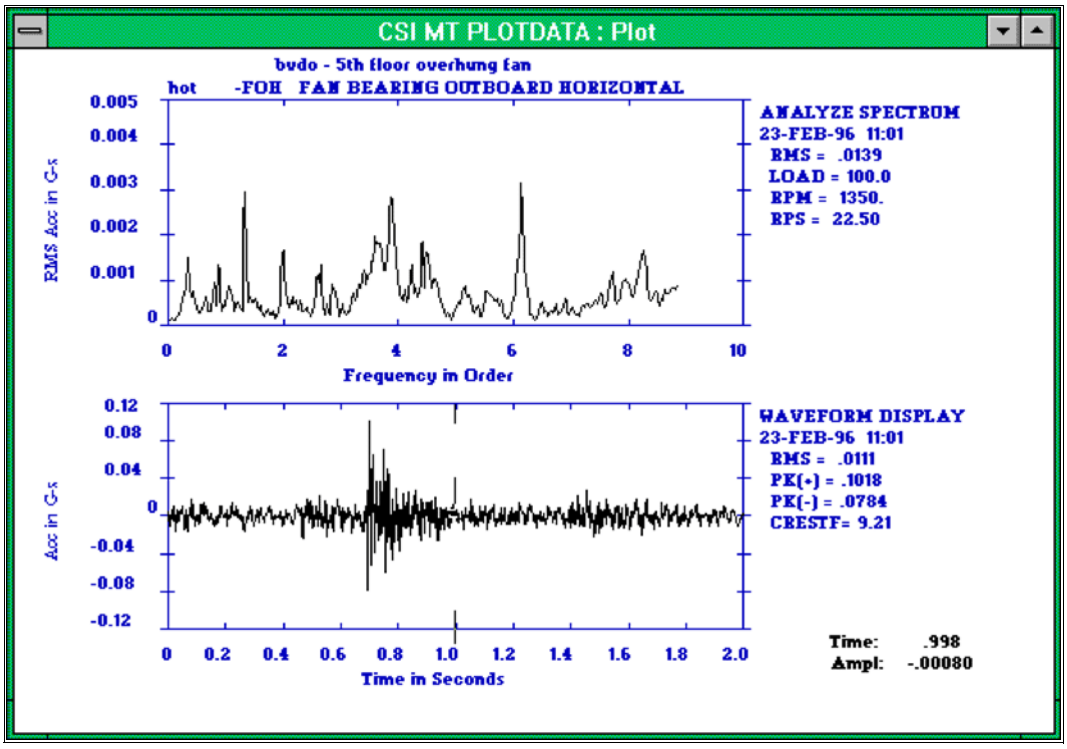

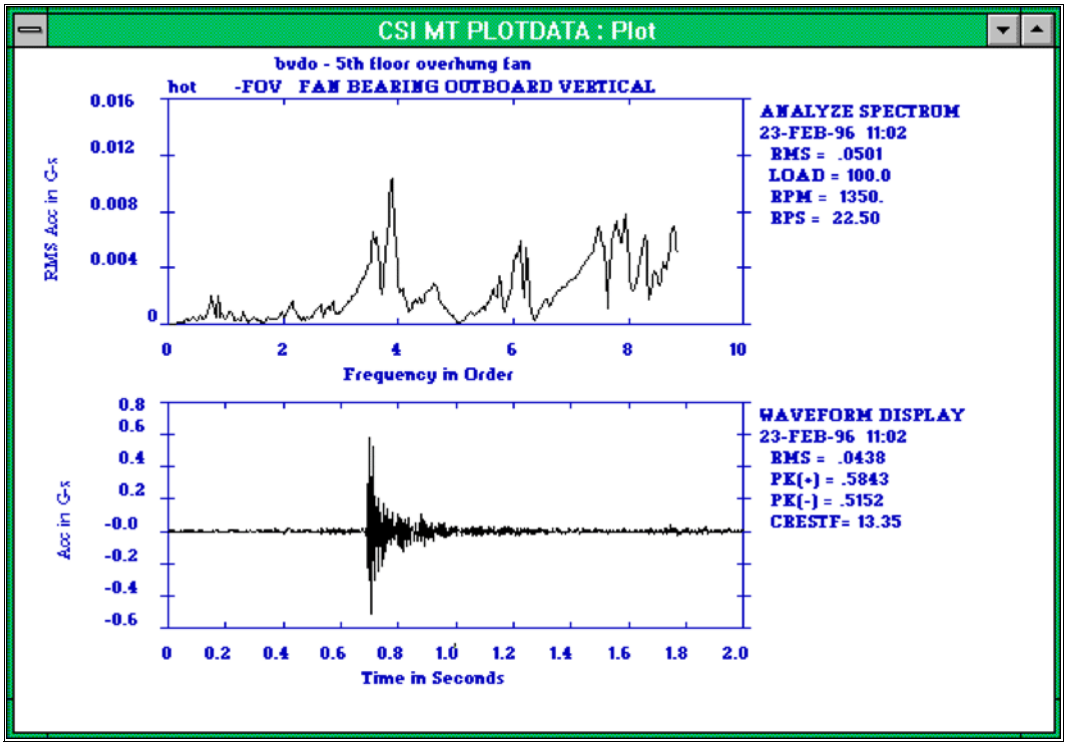

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PHASE DATA

Measurement Point	Amplitude	Phase
FOH	.6 ips	242
FOV	.6 ips	315
FOA	.6 ips	99*
FIH	1.0 ips	248
FIV	1.4 ips	245
FIA	.8 ips	266*

Note

**Vibration transducer orientation was out of phase for axial data.*

After Alignment / Looseness Correction

Measurement Point	Amplitude	Phase
FOH	.92 ips	213
FOV	.65 ips	183
FIH	.74 ips	258
FIV	.67 ips	342

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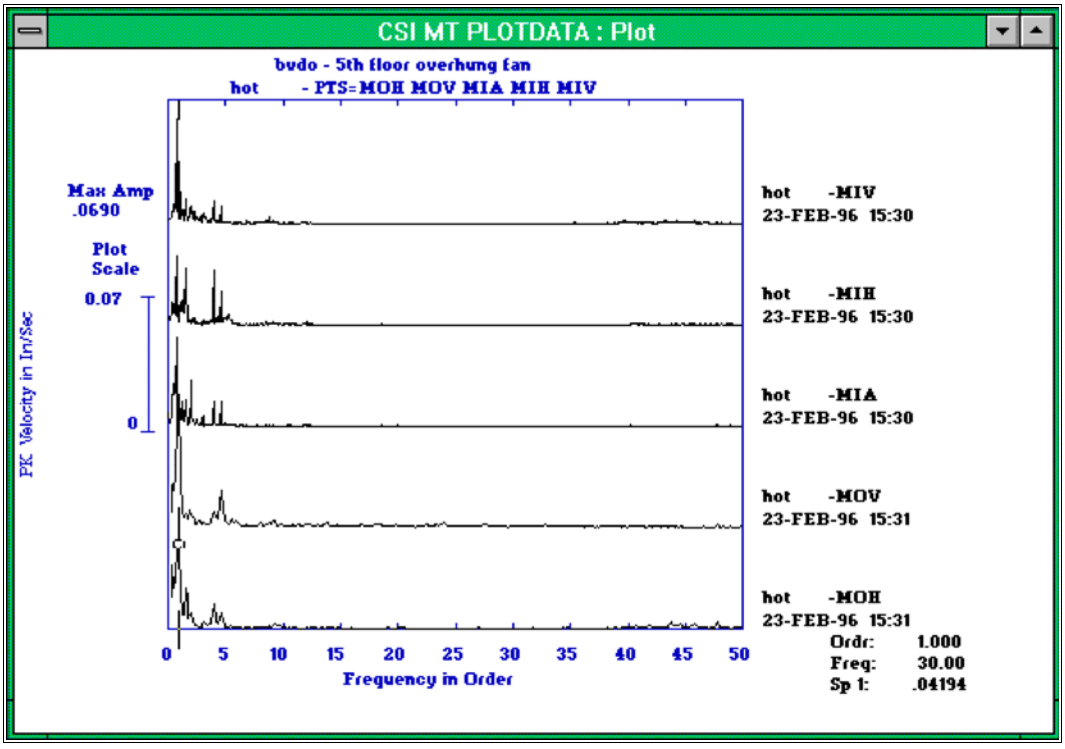
After Balancing

Measurement Point	Amplitude	Phase
FOH	.07 ips	298
FOV	.08 ips	14
FIH	.07 ips	319
FIV	.08 ips	49



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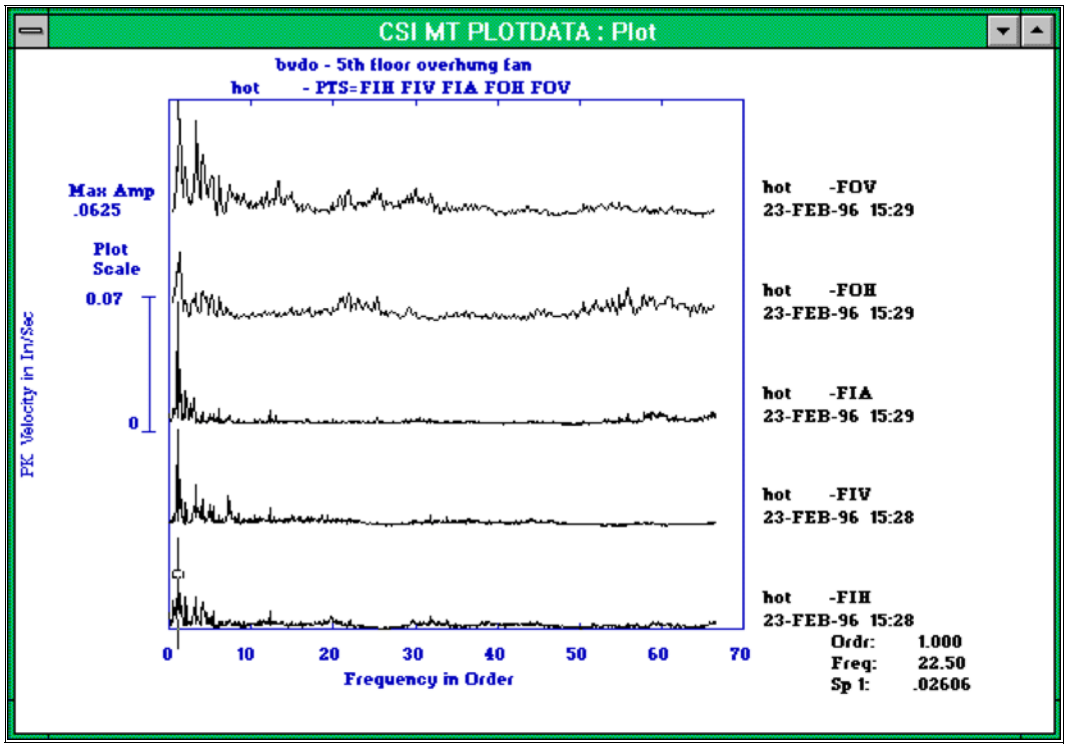

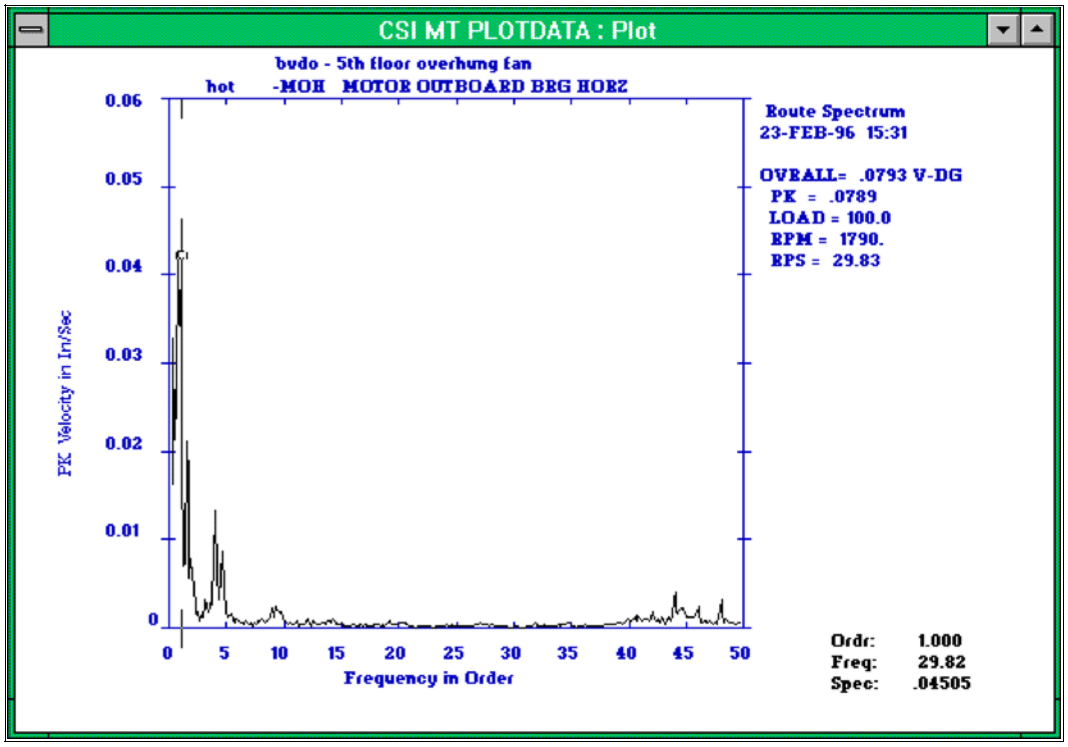

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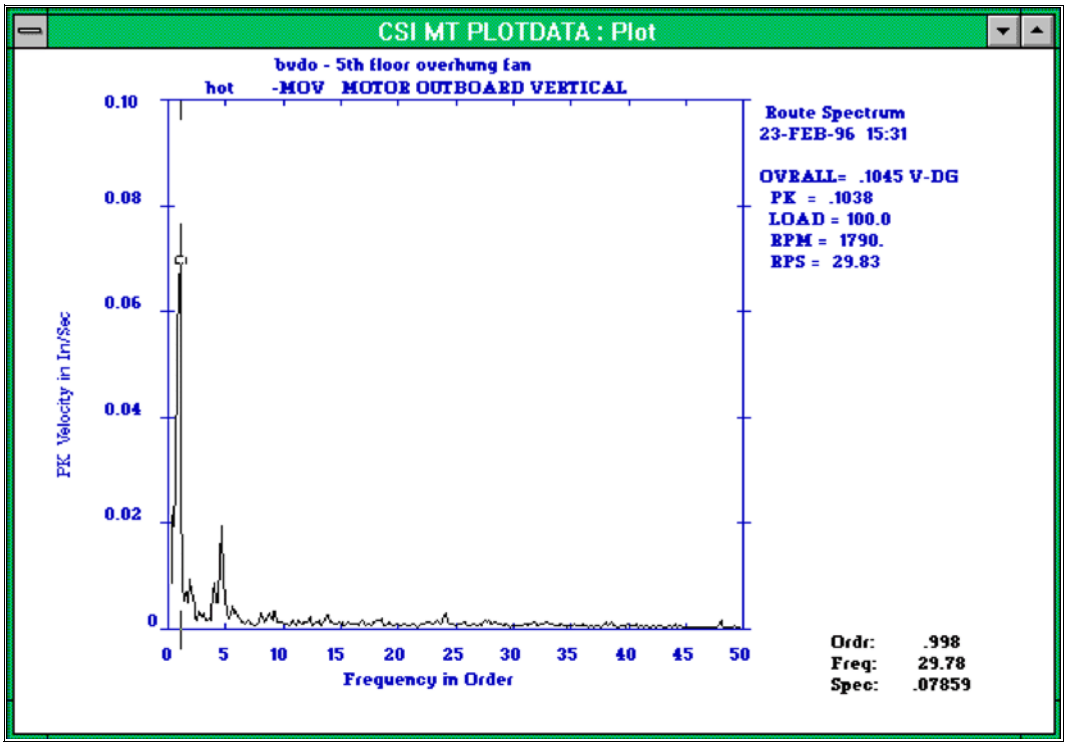

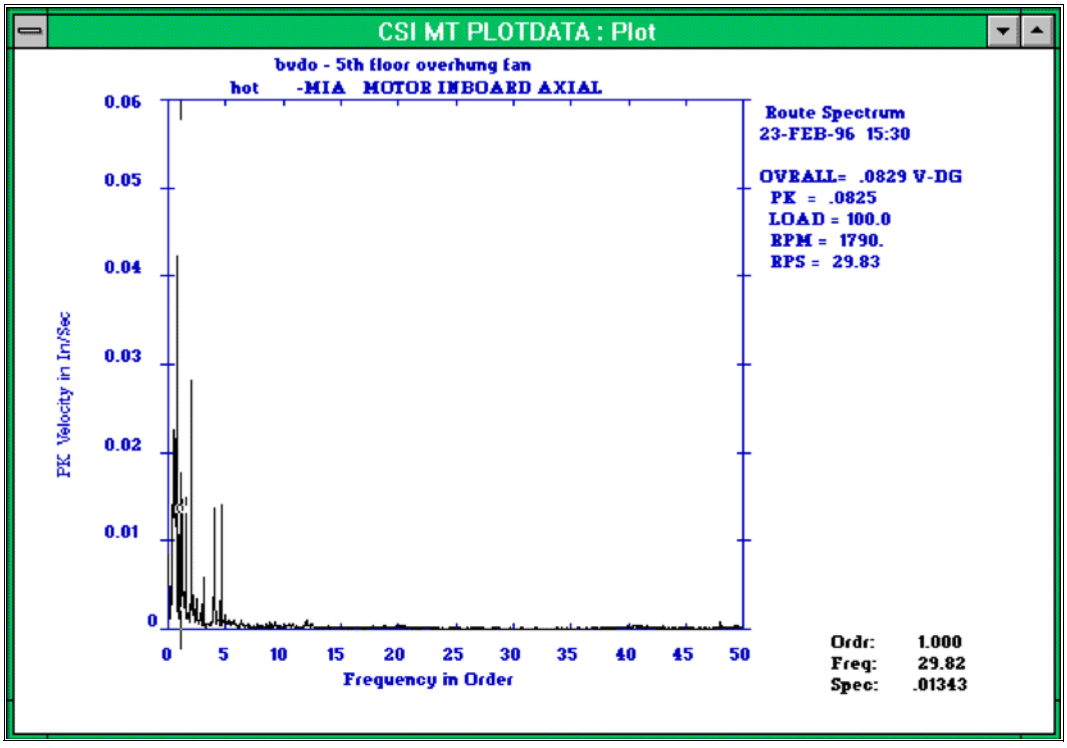

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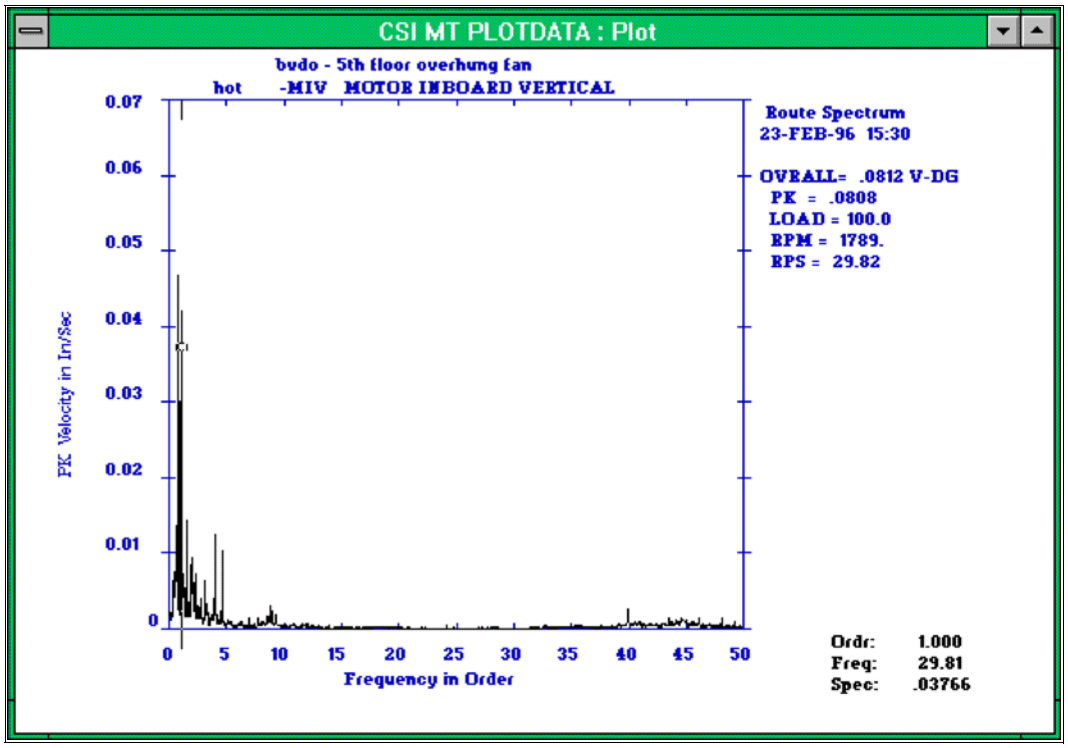

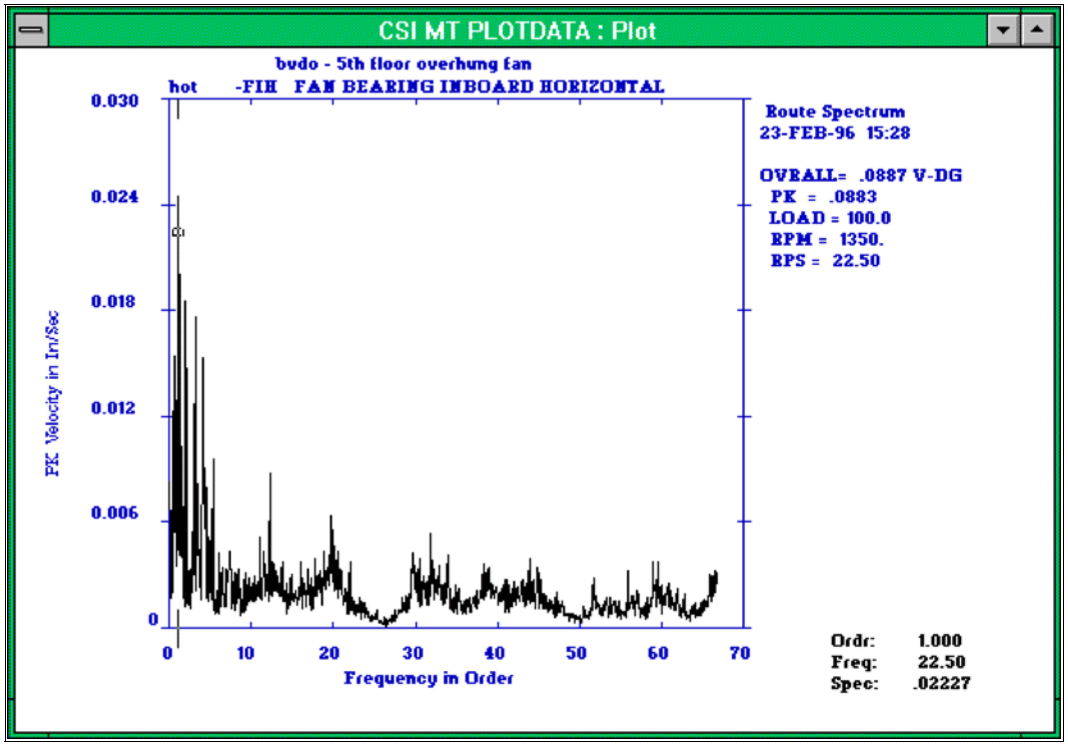

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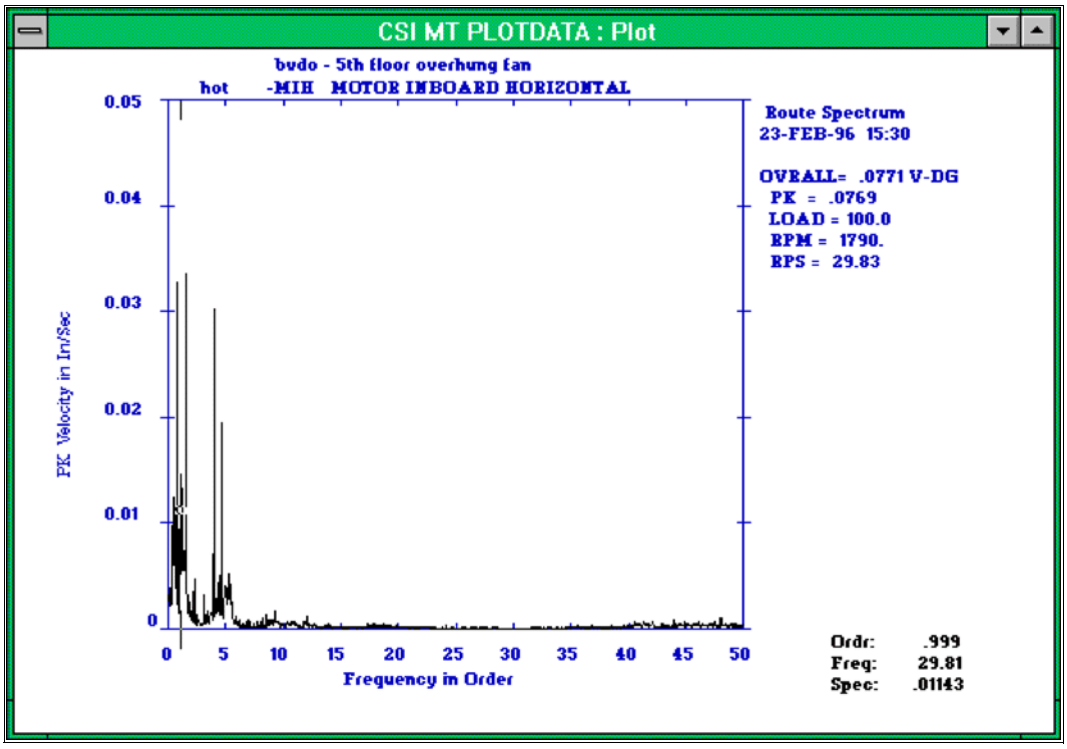

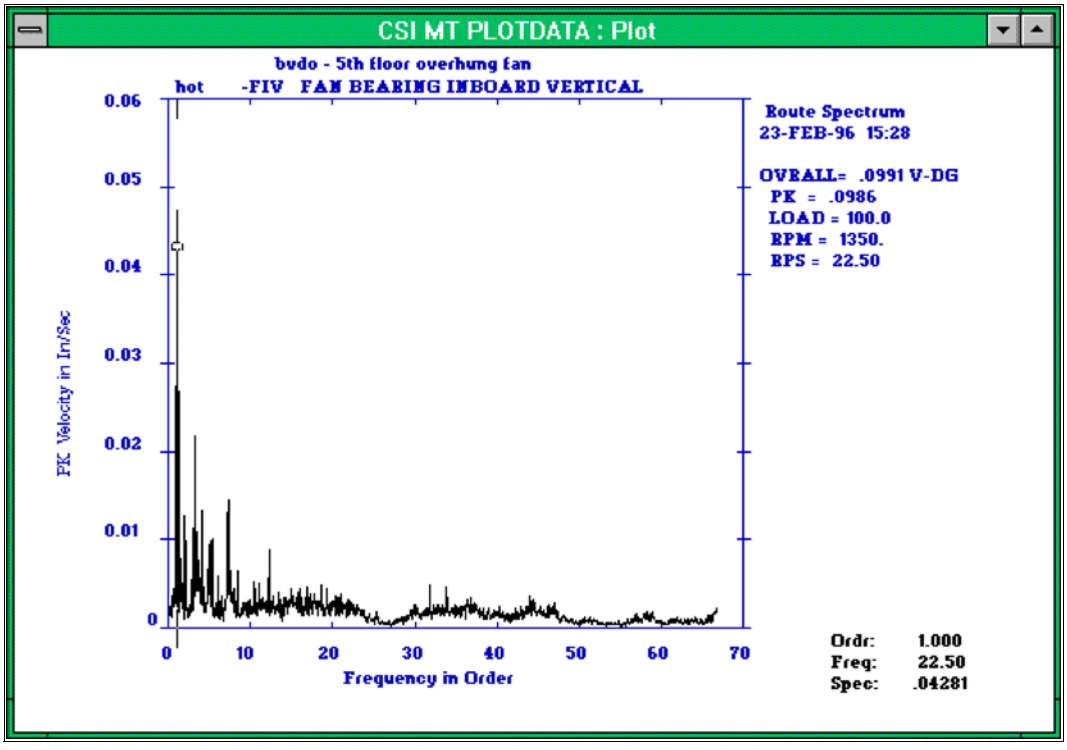

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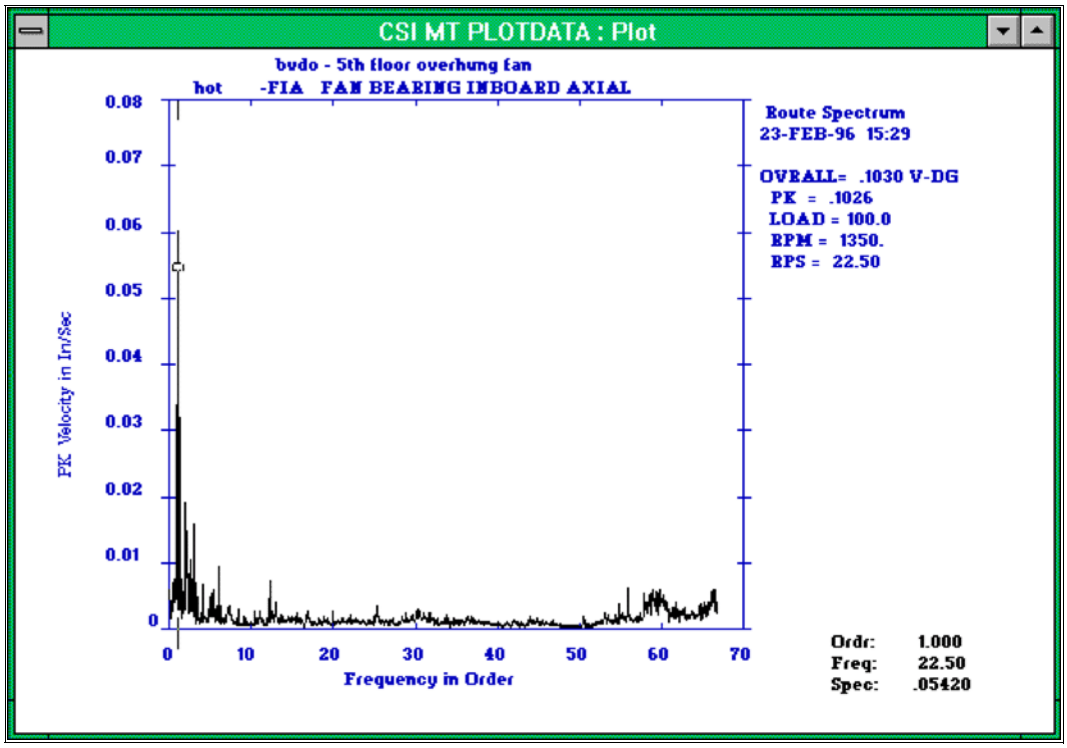

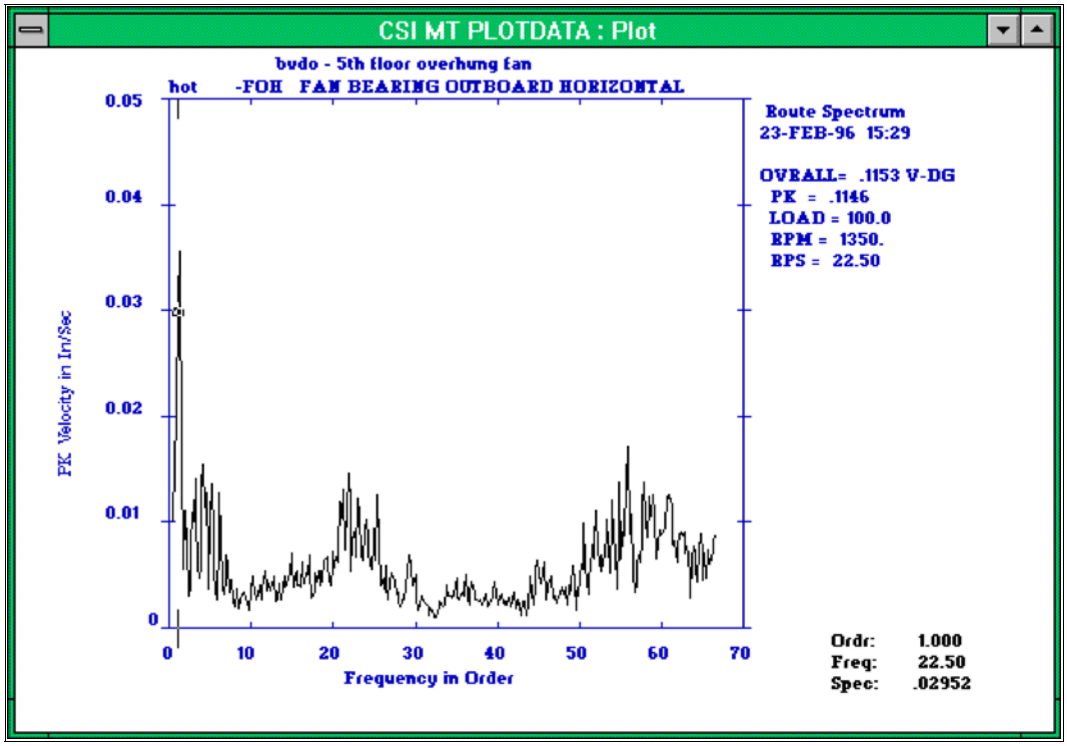

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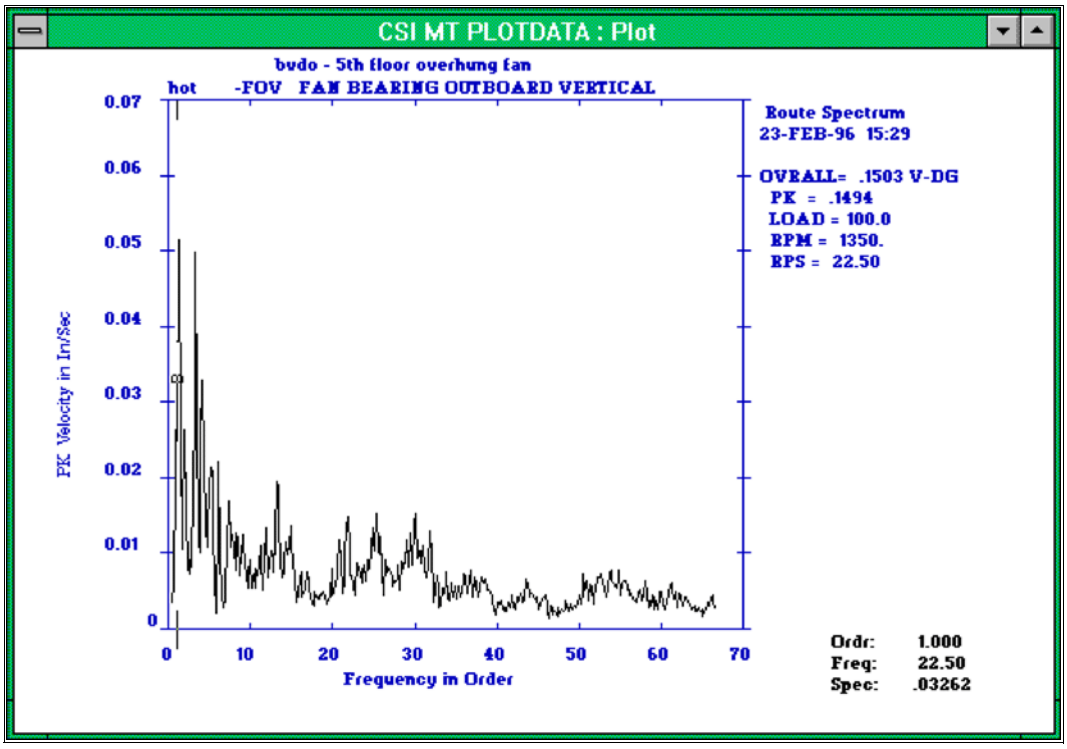

Now, with the data provided, formulate your analysis of this machine.

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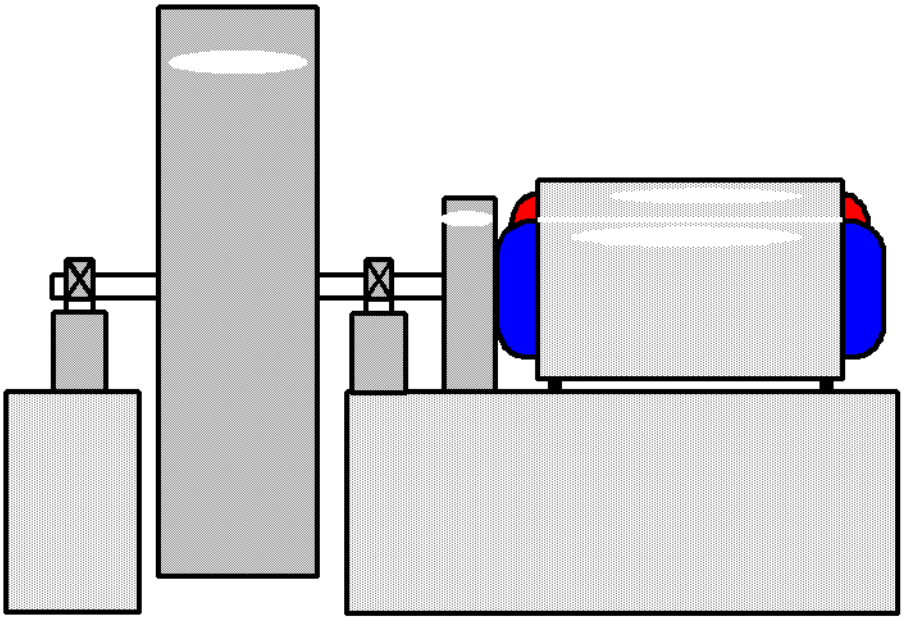
Case History #2 - Direct Driven Fan



Machine Information:

- 450 HP
- 720 RPM
- Direct Driven
- AC Induction Motor
- Overhung Fan

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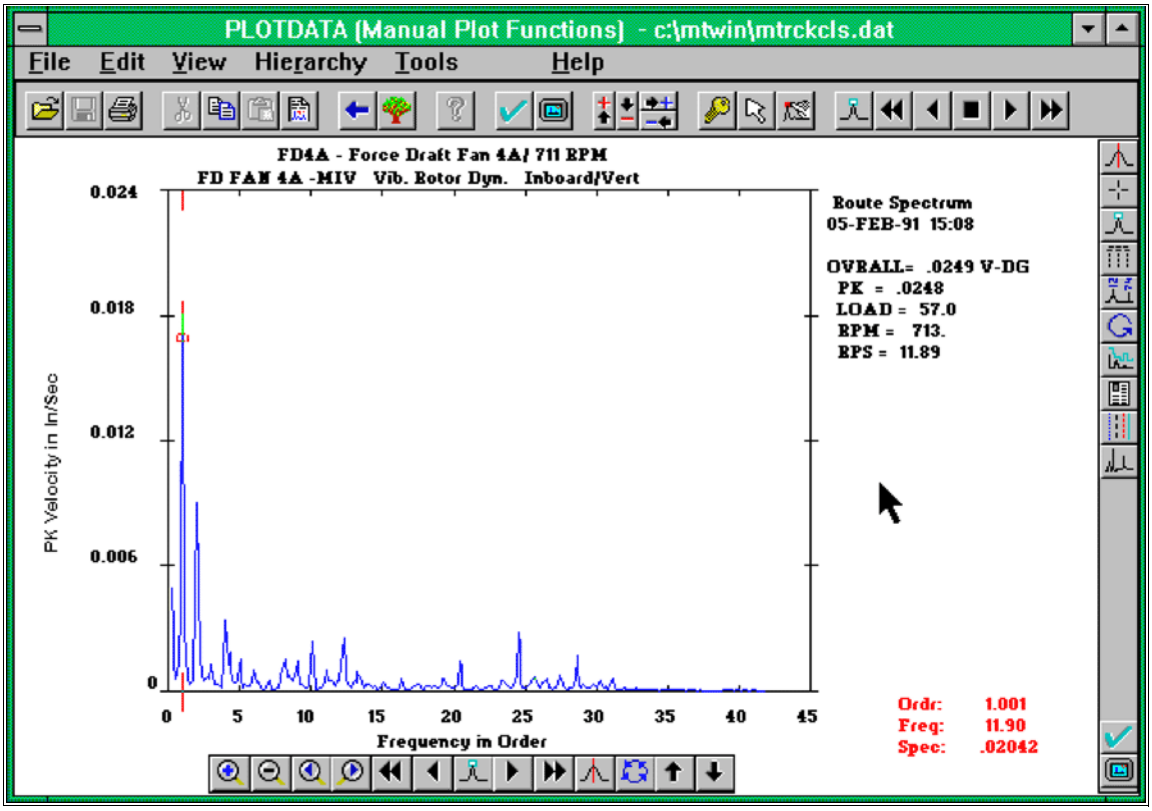

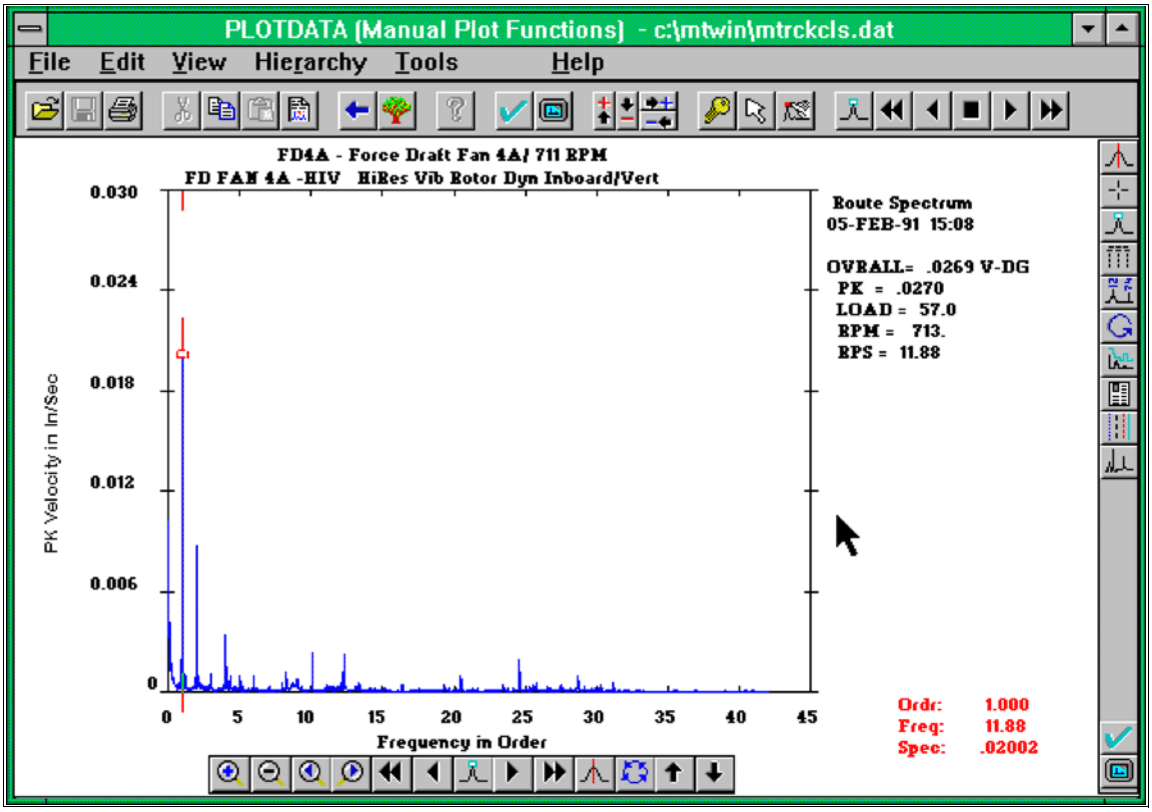

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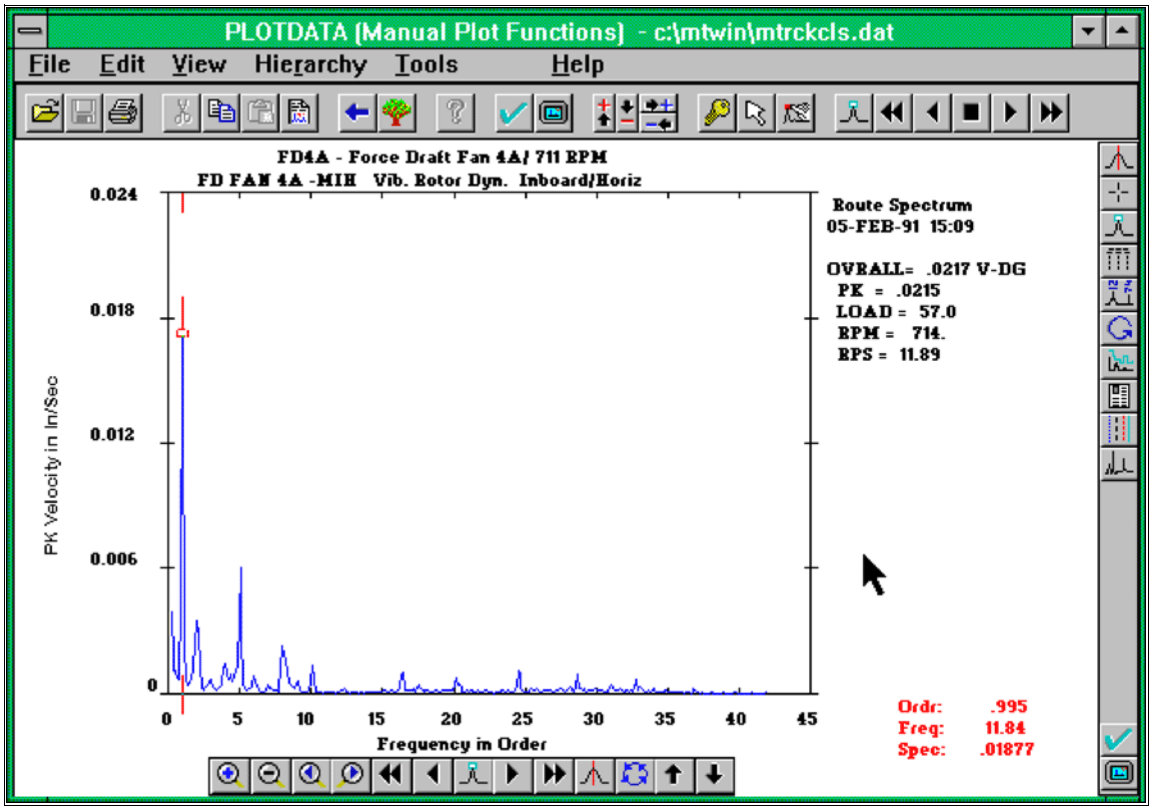

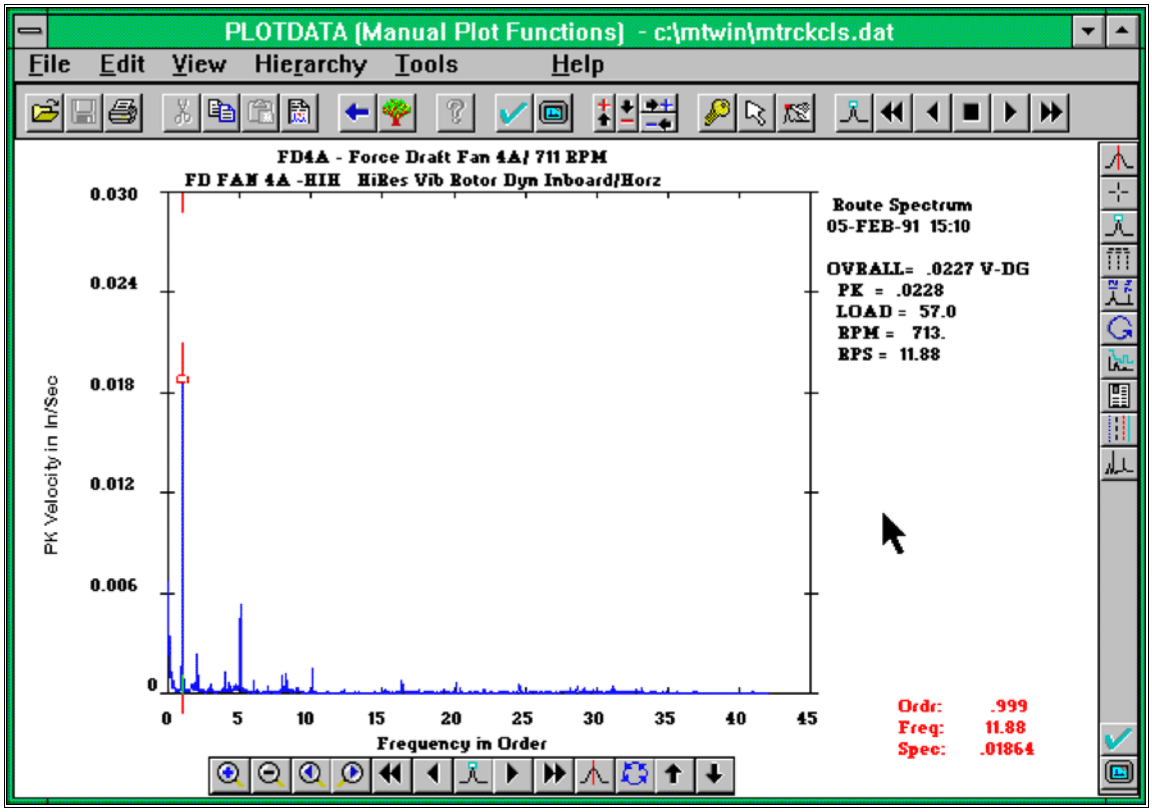

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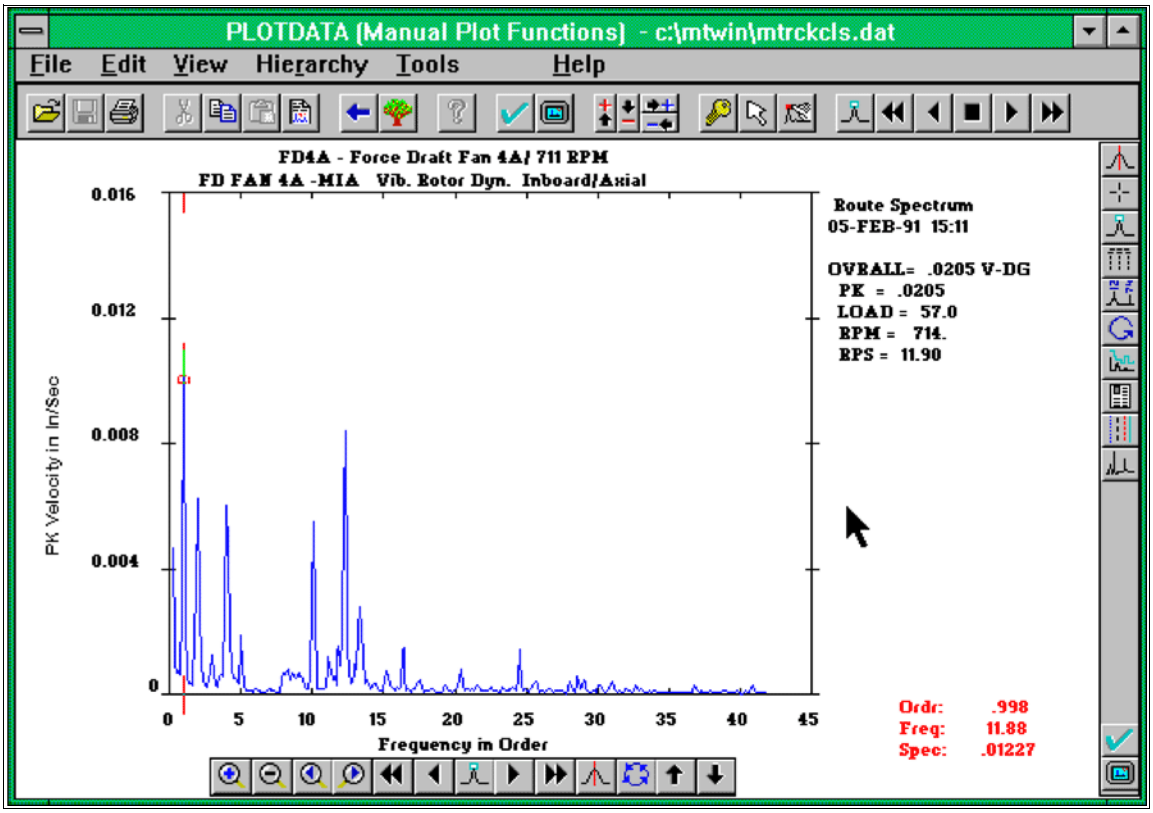

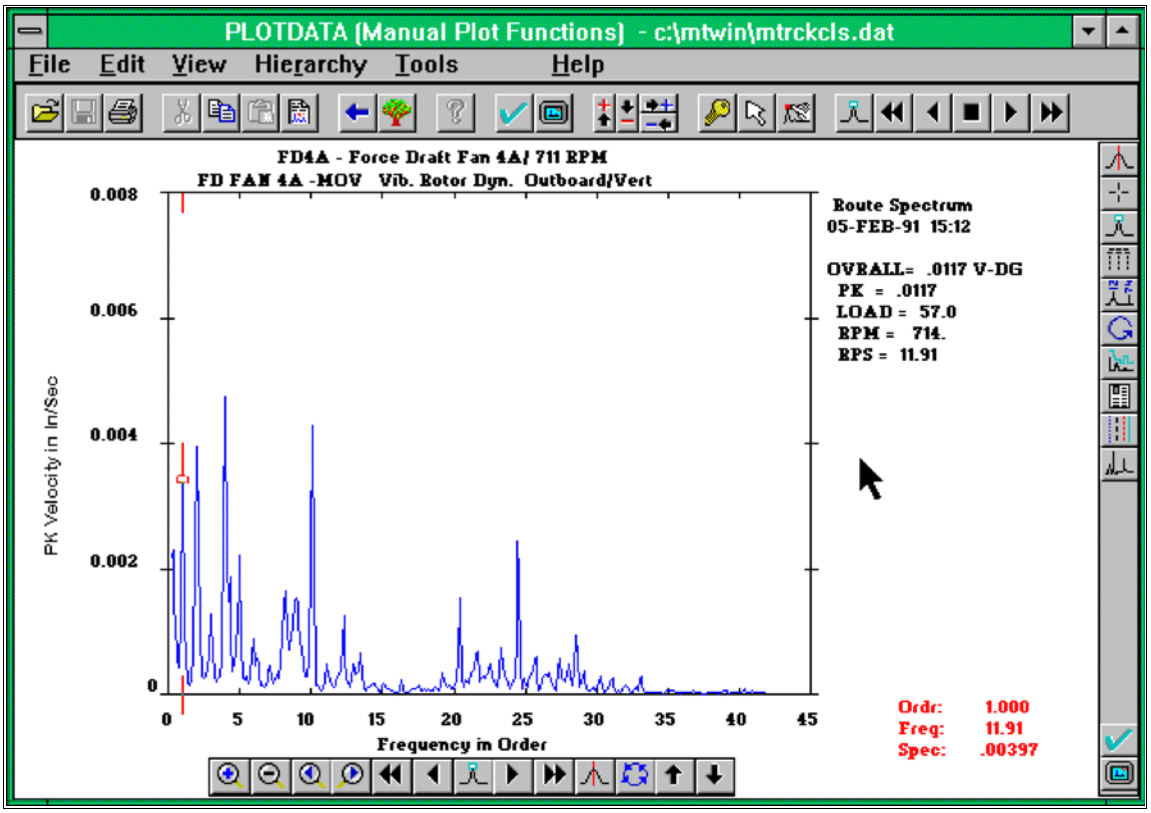

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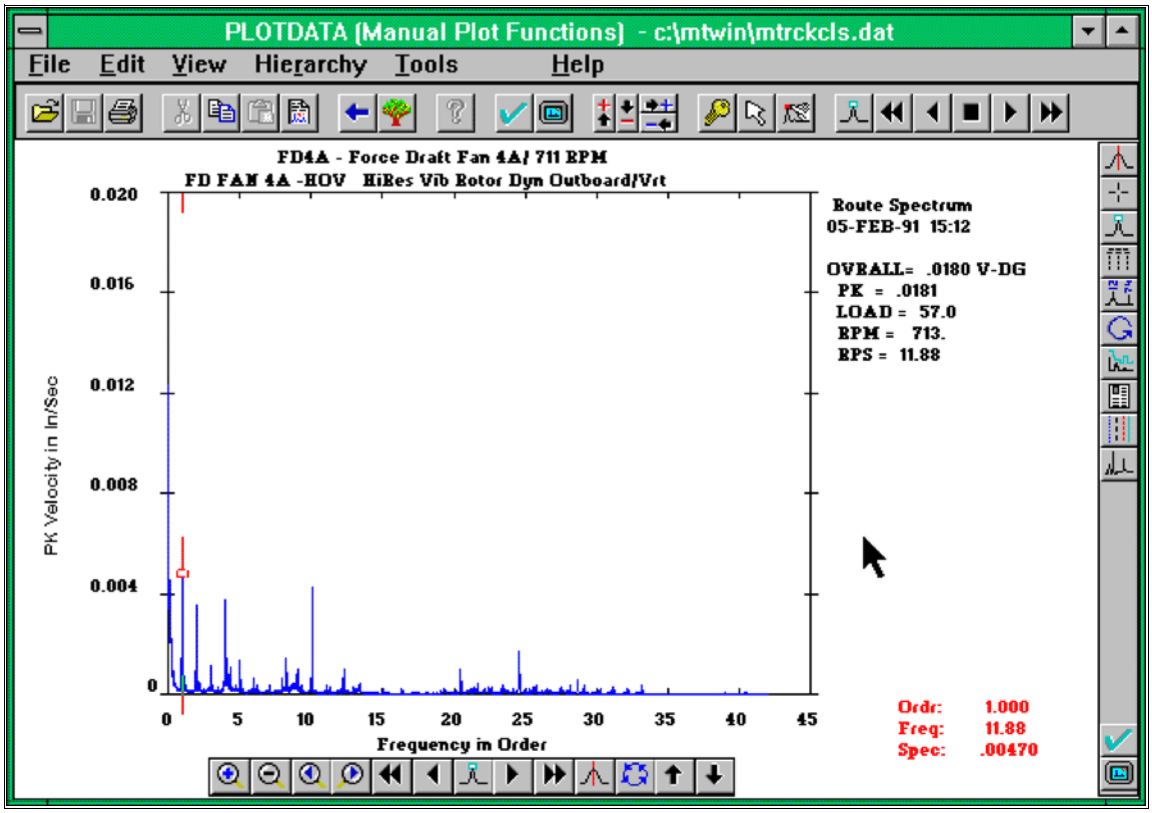

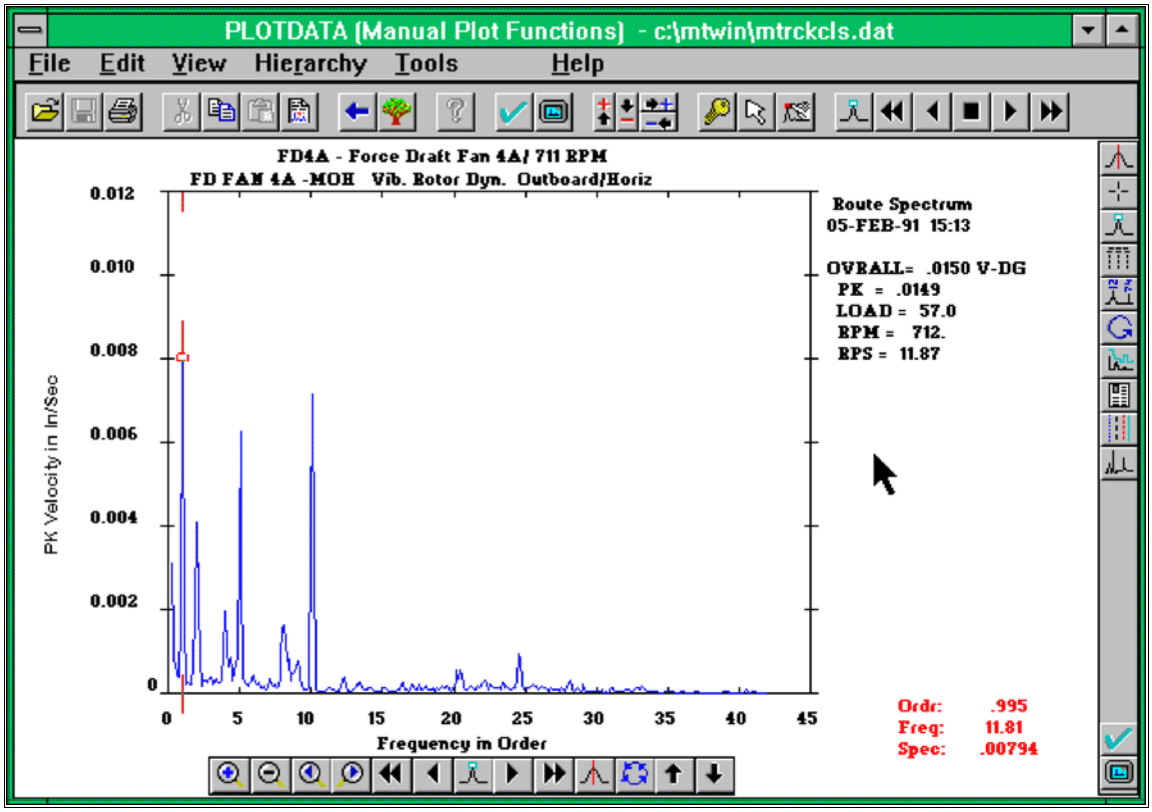

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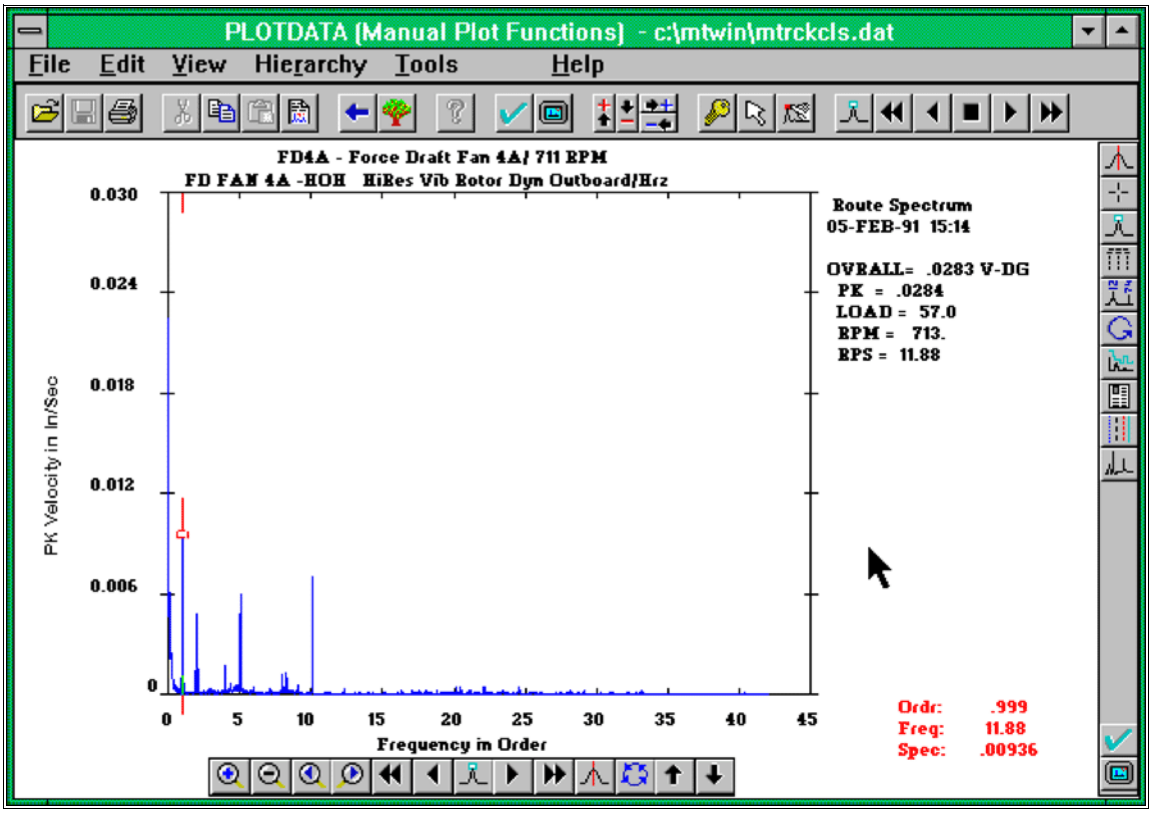

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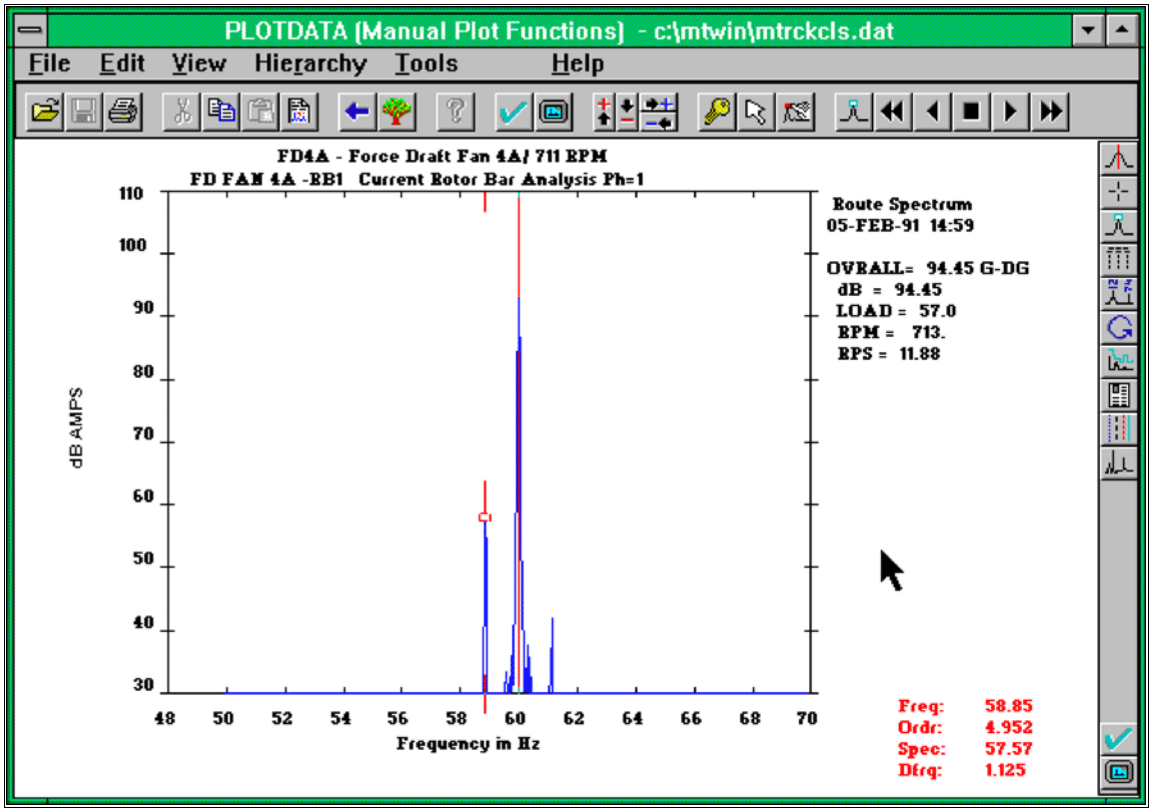
Additional Information CASE HISTORY #2



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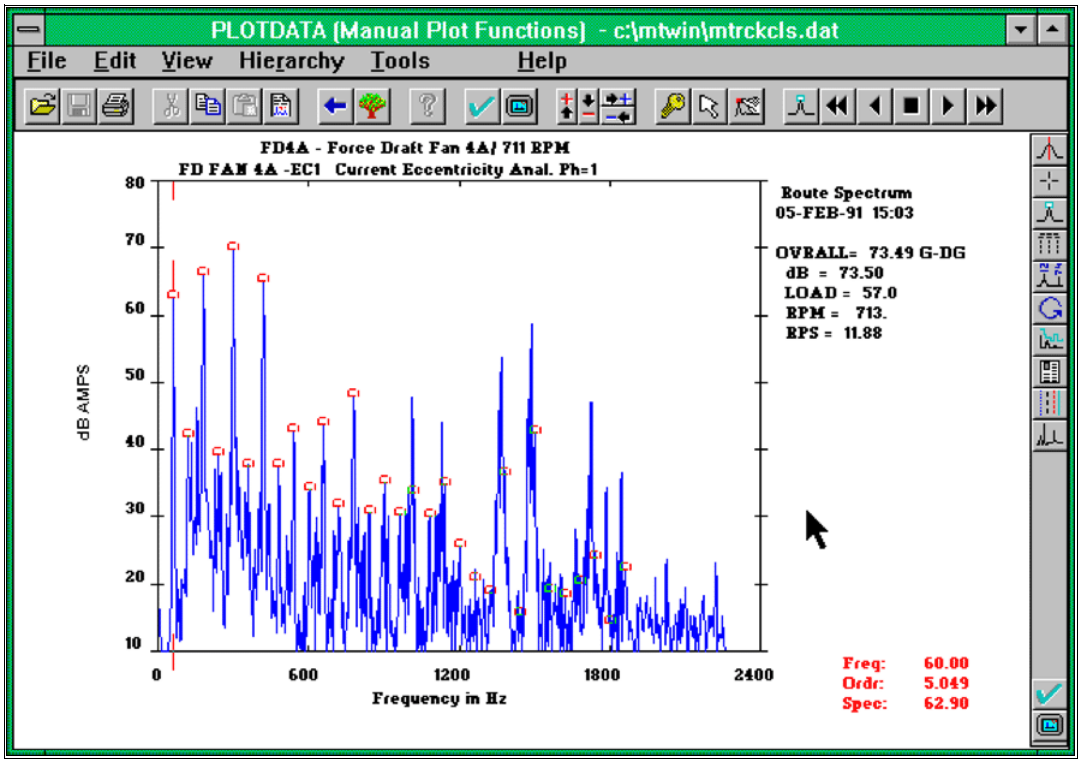

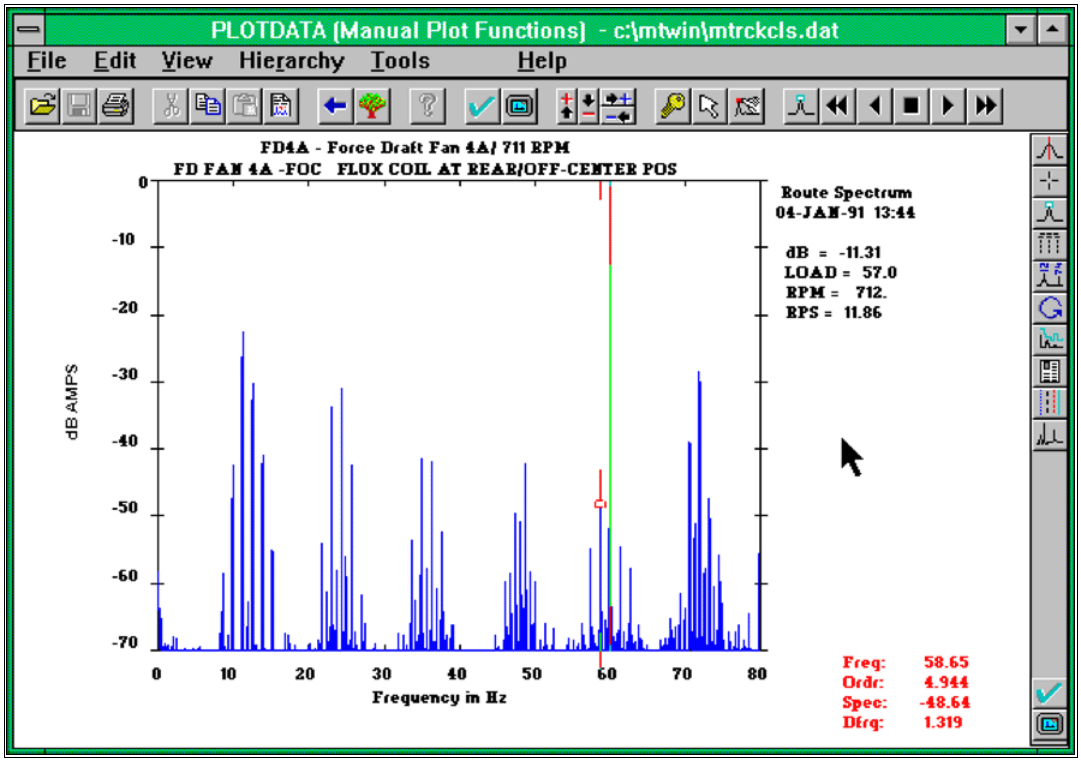

With the data provided, determine the problem with this machine.

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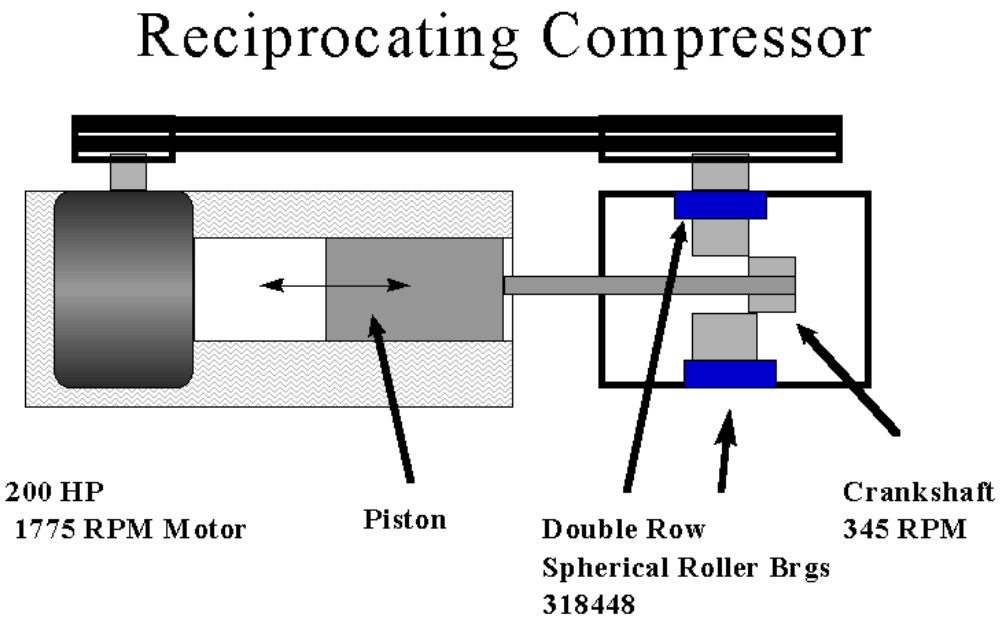
Case History #3

This machine is a reciprocating nitrogen gas compressor at a gas production facility.



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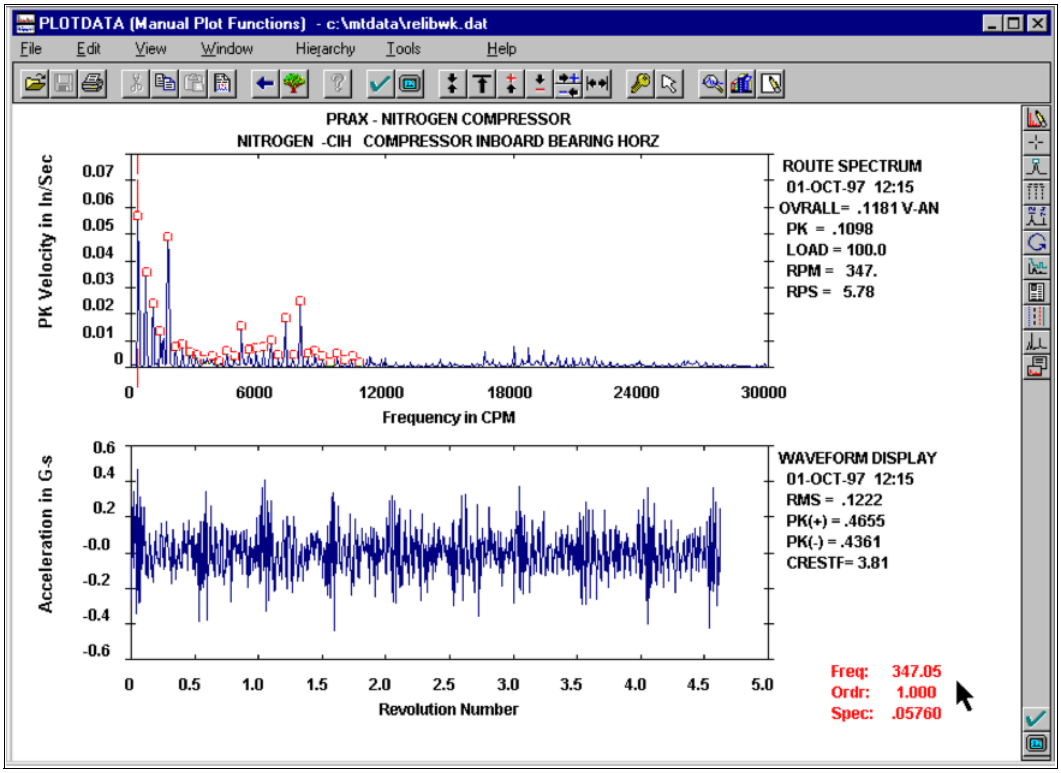
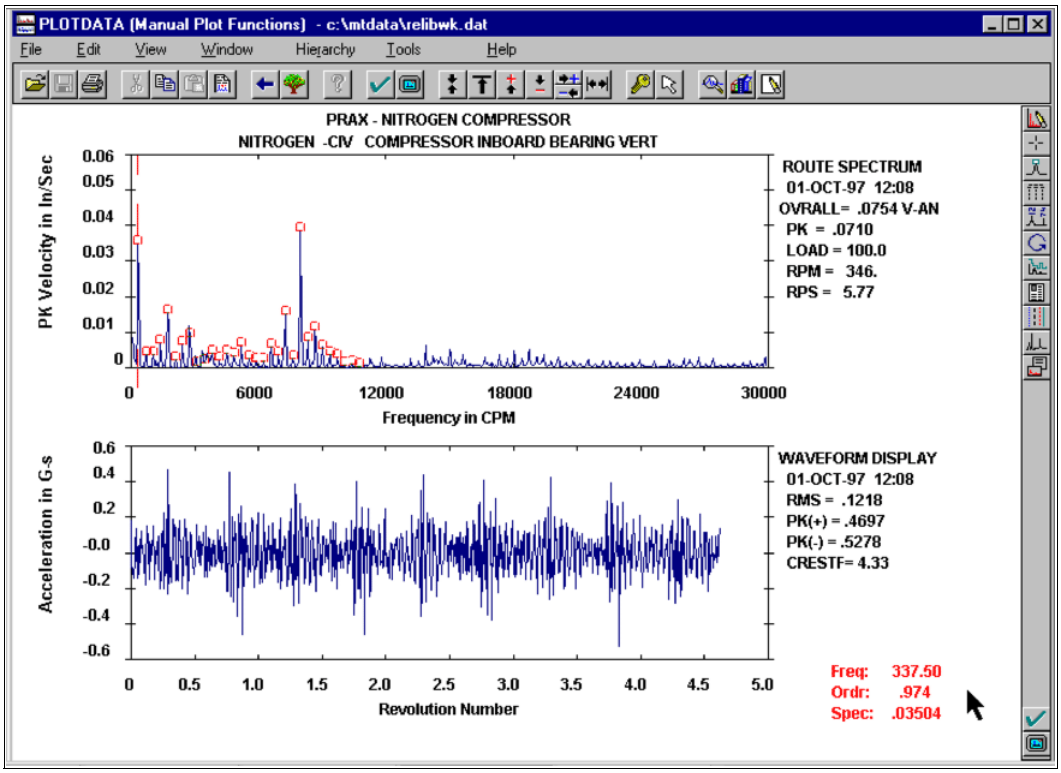
Route Data





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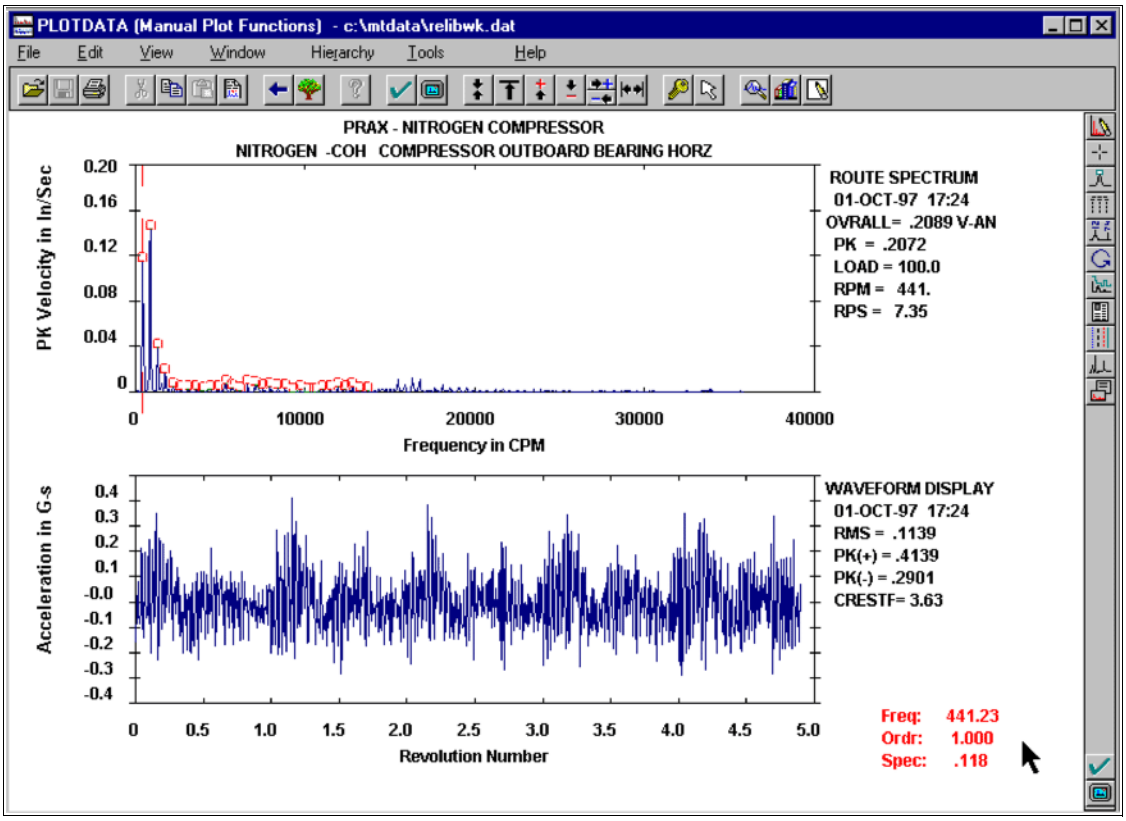

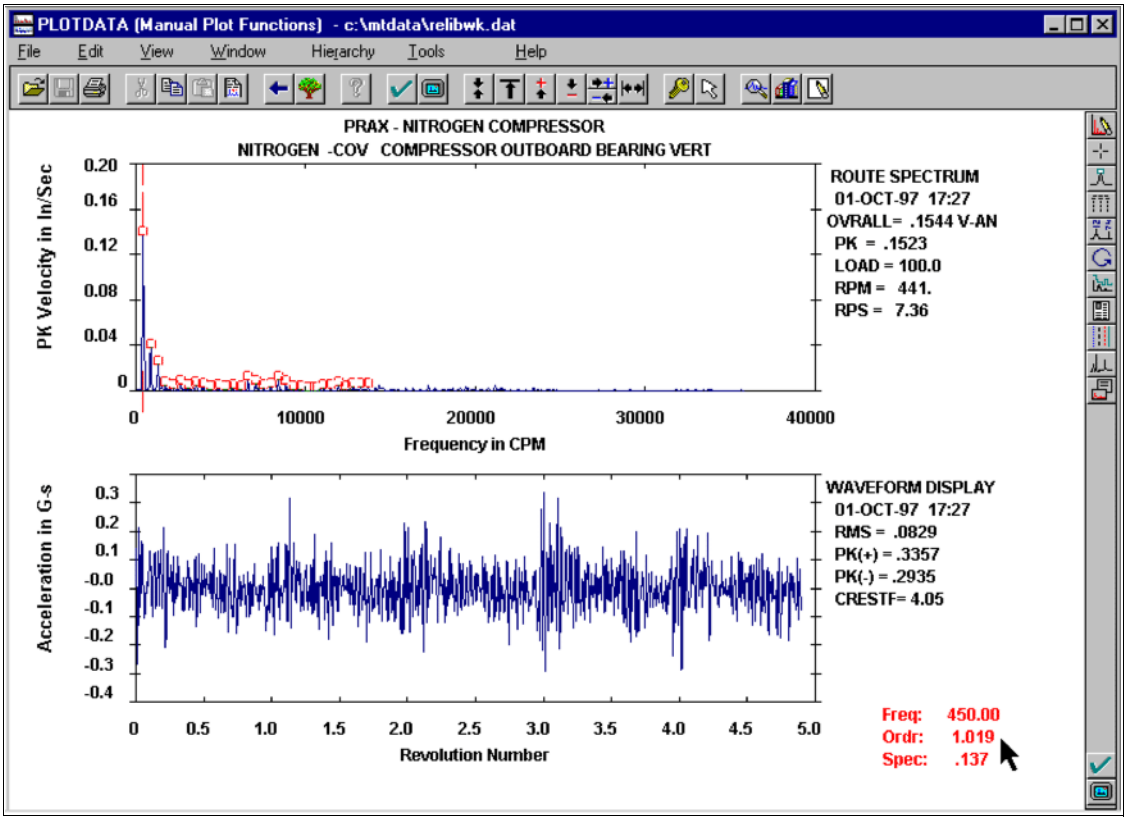

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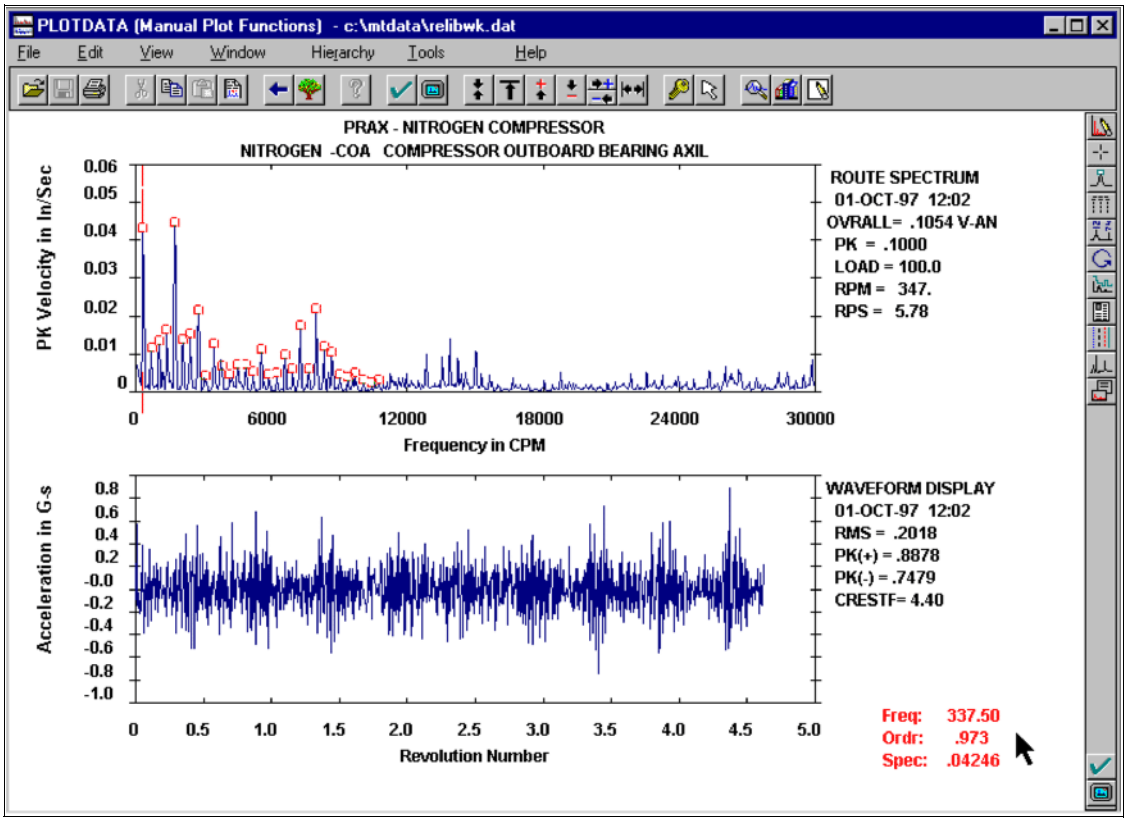

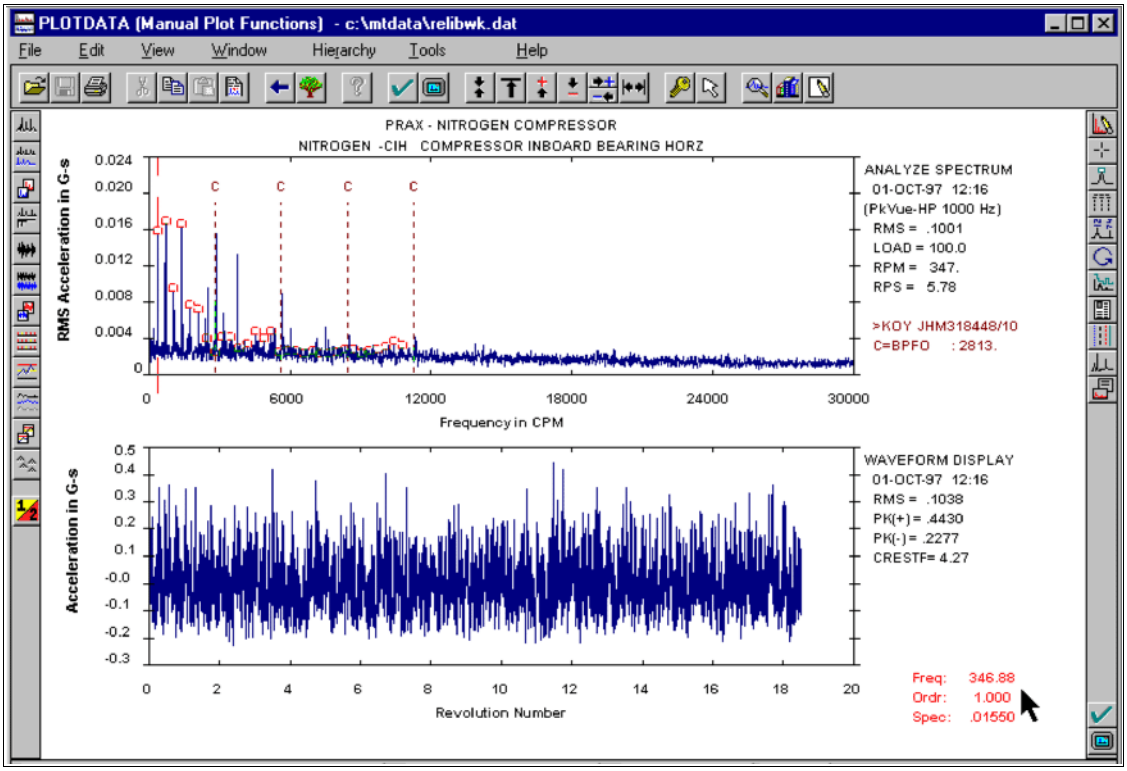

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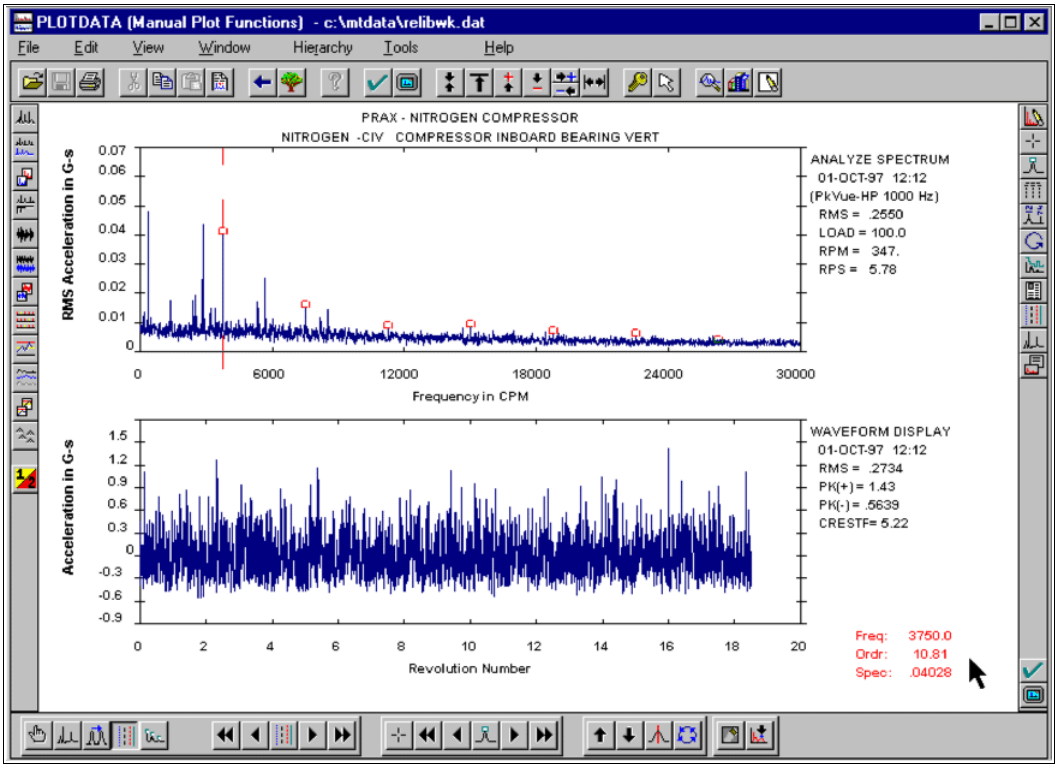
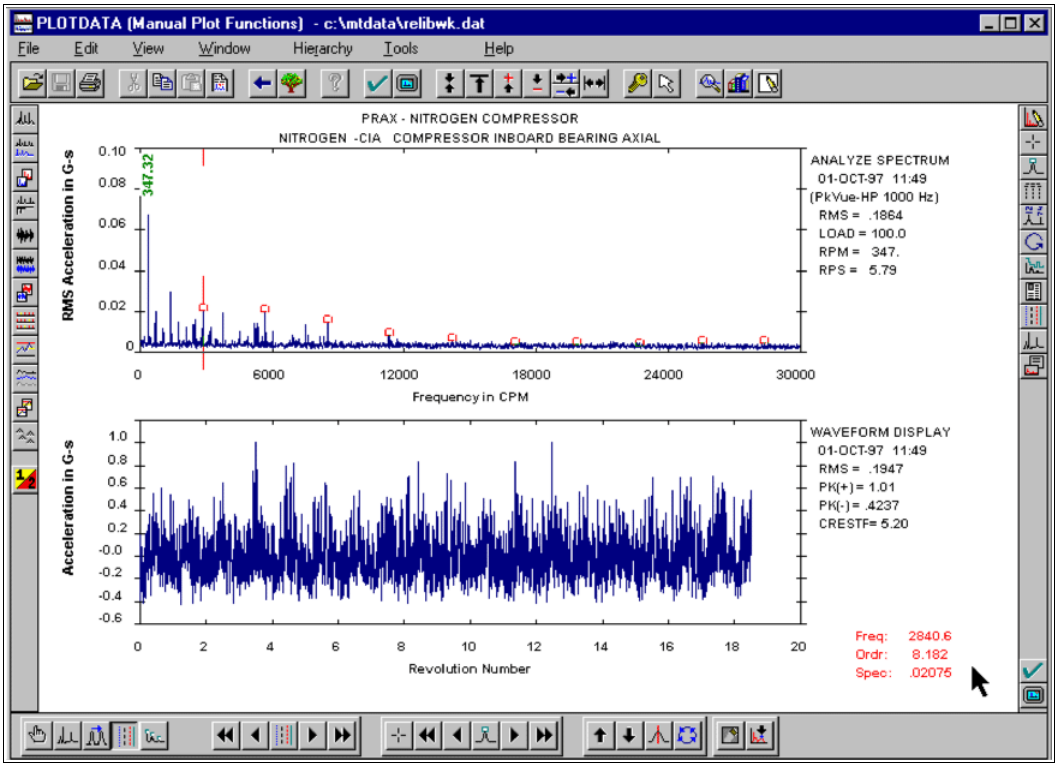
PeakVue Data





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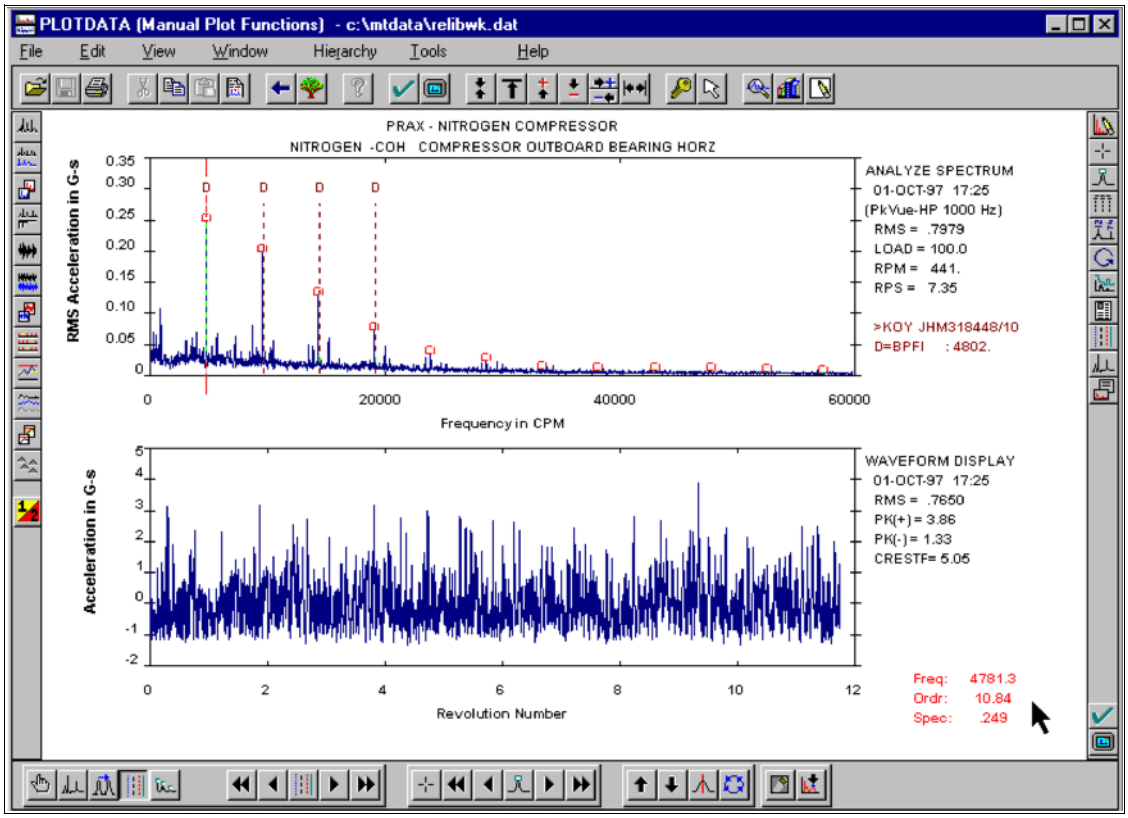

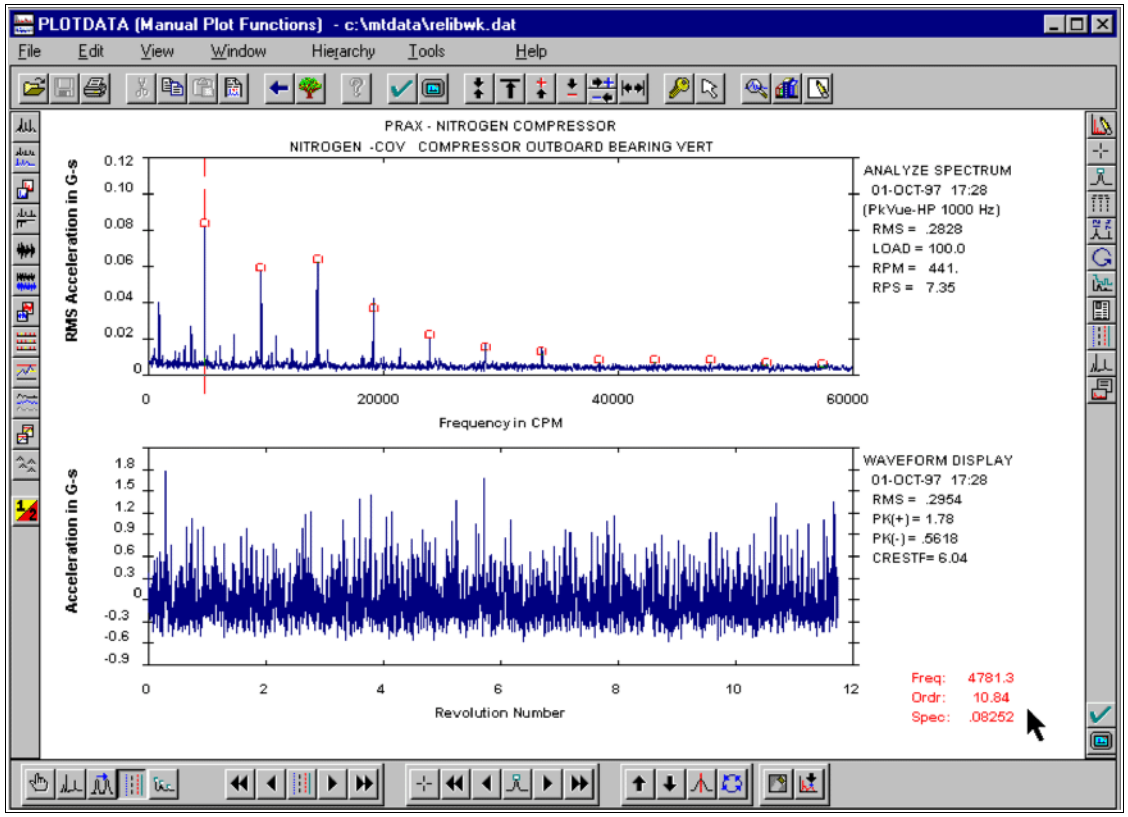

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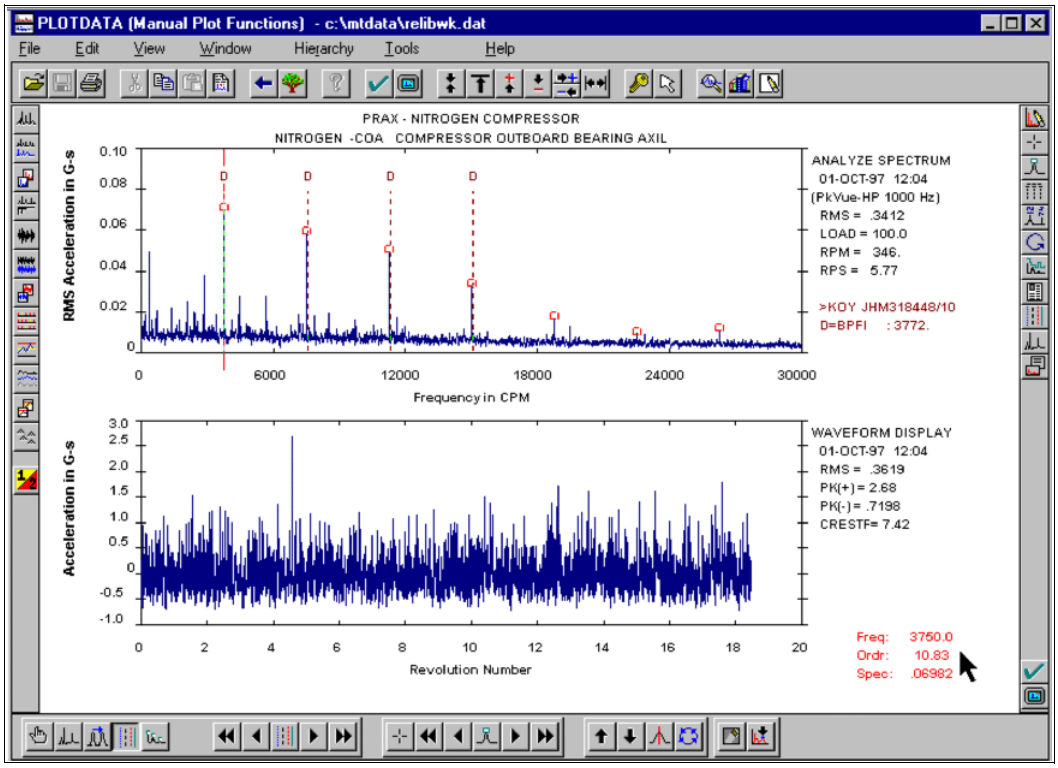

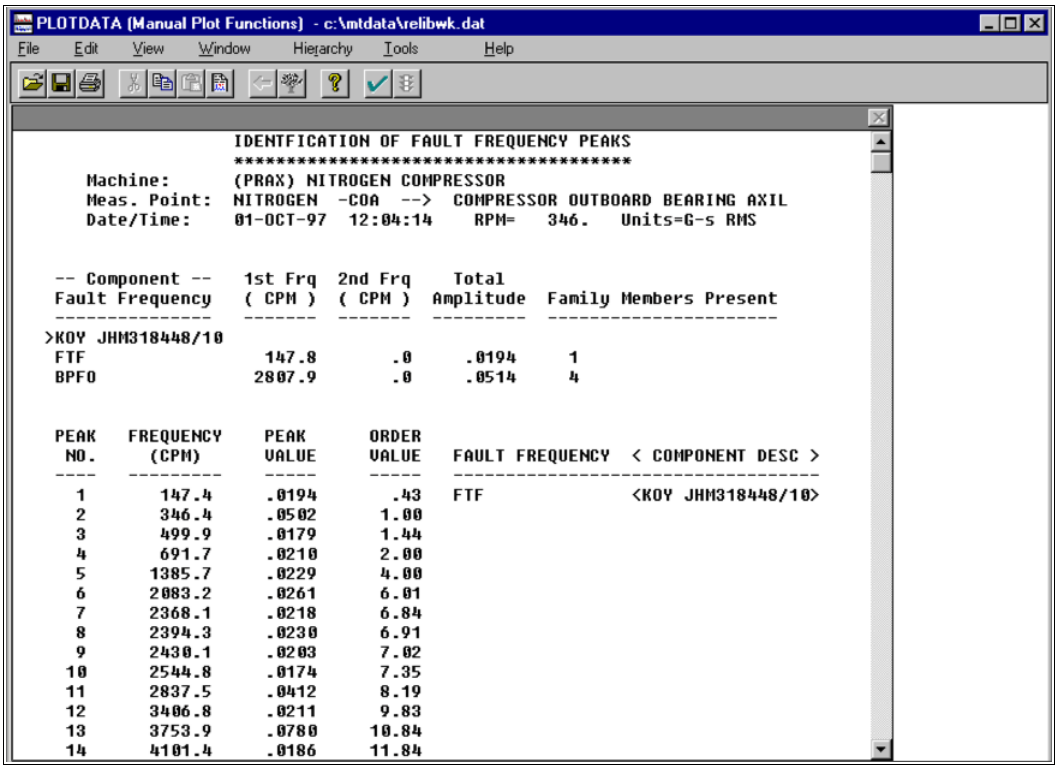
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File Edit View Window Hierarchy Tools Help
IDENTFICATION OF FAULT FREQUENCY PEAKS
Machine: (PRAX) NITROGEN COMPRESSOR
Meas. Point: NITROGEN -COA --> COMPRESSOR OUTBOARD BEARING AXIL
Date/Time: 01-OCT-97 12:04:14 RPM= 346. Units=G-s RMS
-- Component -- Fault Frequency | 1st Frq (CPM) | 2nd Frq (CPM) | Total Amplitude | Family Members Present
>KOY JHM318448/10
FTF 147.8 .0 .0194 1
BPFO 2807.9 .0 .0514 4
PEAK NO. | FREQUENCY (CPM) | PEAK VALUE | ORDER VALUE | FAULT FREQUENCY | < COMPONENT DESC >
1 147.4 .0194 .43 FTF <KOY JHM318448/10>
2 346.4 .0502 1.00
3 499.9 .0179 1.44
4 691.7 .0210 2.00
5 1385.7 .0229 4.00
6 2083.2 .0261 6.01
7 2368.1 .0218 6.84
8 2394.3 .0230 6.91
9 2430.1 .0203 7.02
10 2544.8 .0174 7.35
11 2837.5 .0412 8.19
12 3406.8 .0211 9.83
13 3753.9 .0780 10.84
14 4101.4 .0186 11.84

Using the data above, determine the problem with this machine.

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Case Summaries

Case 1: 5th Floor overhung fan

The problems were high fan 1xTS in the axial and radial direction. Angular misalignment of the sheaves caused the high 1xTS in the axial direction, fan unbalance caused the high 1xTS in the radial direction and loose fan mounting bolts caused the multiples of fan TS. Once the unit was balanced, fan bearing problems were visible.

Case 2: Forced Draft fan 4A / 711 rpm

This case requires high resolution data to reveal the problem. The motor has sidebands spaced at slip X # poles around multiples of TS. This indicates a potential problem on the rotor. Current and flux coil data confirm broken rotor bars on the motor.

Case 3: Praxair Nitrogen Gas Compressor

This machine was reported to have inner and outer race bearing defects based on the PeakVue data. It is interesting to note that the route data showed many harmonics of turning speed, but low levels of impacting in the time waveform. A reciprocating compressor will tend to show multiple harmonics of turning speed in the standard vibration data. Because of this, the standard vibration data is somewhat inconclusive. Examination of the old bearings after rebuild revealed a stage 2 bearing failure with spalls on both the inner and outer races.

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Case History #4

Sudden, violent vibration increases on a production fan

Background

The fan is a single inlet, overhung, direct coupled, 3555 rpm fan supplying ambient temperature air to a production line. Airflow, speed and temperature are steady during production. Velocity transducers, mounted to the fan bearings, are connected to a vibration switch set to trip the fan at 0.8 inches per second (IPS). Figure 1 is a representation of the fan and motor showing the measurement point locations.

Equipment Used

- Computational Systems, Inc. 2120 signal analyzer
- Laser Tachometer
- MachineView portable monitoring system
- Transient Capture

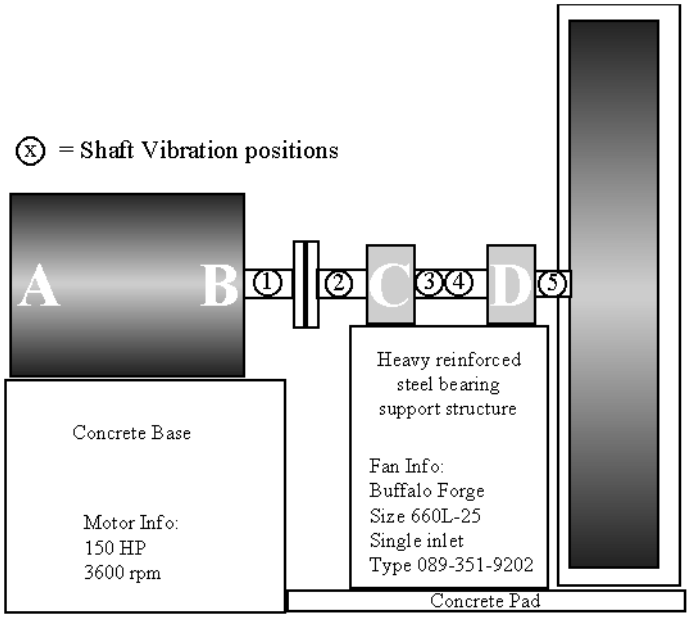

Figure 1 - Fan Diagram with Measurement Point Locations

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Problem

The vibration monitor trips the fan off-line several times (randomly) during production.

Investigation

Upon arriving at the plant, the fan was vibrating at a "FAIR" severity level (less than 0.2 inches/second - peak or IPS). The vibrations instantaneously increased to "EXTREMELY ROUGH" (greater than 0.5 IPS) for about 20 seconds then returned to the fair range. This condition repeated randomly. The periods of increased vibration will be referred to as "events". At times the events looked periodic. When the vibrations increase to more than 0.8 ips, the on-line system tripped the fan off-line and brought down production. Figure 2 is a time capture (transient capture) of the vibrations on the "D" bearing (outboard fan bearing horizontal direction) showing the pattern of the increased vibration over a 30 minute interval.

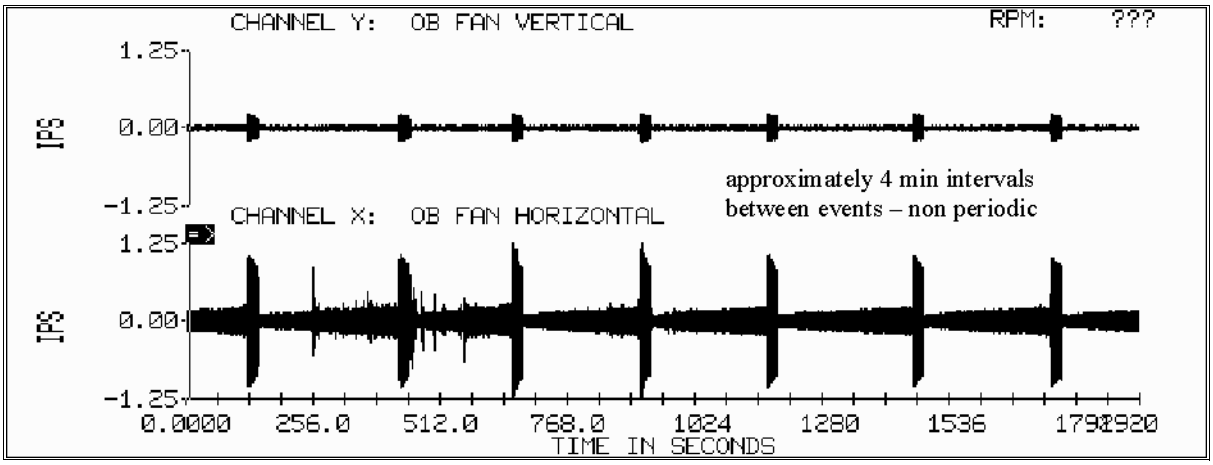

Figure 2 - Time Capture Showing Vibration Events at Regular Intervals (outboard fan bearing - horizontal directions - IPS peak)

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The events are typical of the fan's performance over the past several years. The events sometimes trip the vibration monitor and stop production. The fan was balanced on several occasions. In the recent past, a new shaft and a new, slightly heavier, fan rotor were installed on the machine in an attempt to eliminate the events. It did not. The new fan rotor was removed because it did not improve the vibration. The old fan rotor was reinstalled and balanced. The problems continued.

On two occasions, during the first morning of the service visit, the fan was stopped and restarted. Figures 3 and 4 are one-hour time captures of the outboard fan bearing horizontal vibration. Figure 3 shows no events occurred after the first start-up. Figure 4 shows that events began immediately after the second start-up. The interval between the events was not constant. The intervals grew longer after each event until, as figure 5 shows, the events stopped suddenly in the second hour of run time.

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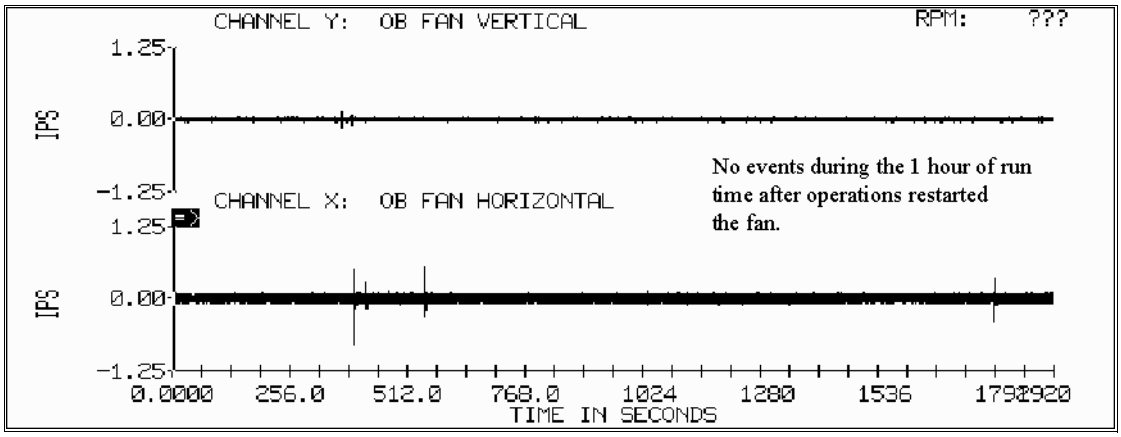

Figure 3 - Time Capture Showing Vibration Events after 1st start-up (outboard fan bearing - horizontal direction - IPS peak)

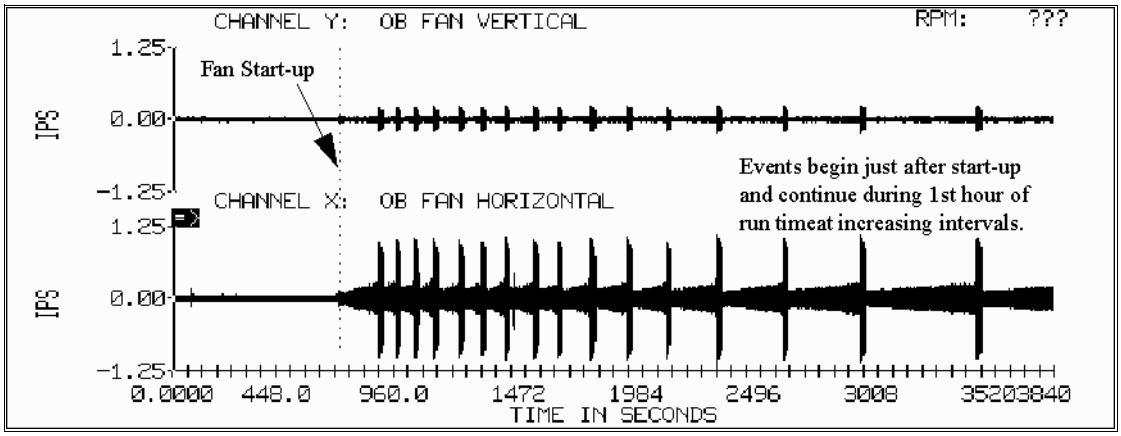

Figure 4 - Time Capture Showing Vibration Events after 2nd start-up (outboard fan bearing - horizontal direction - IPS peak)

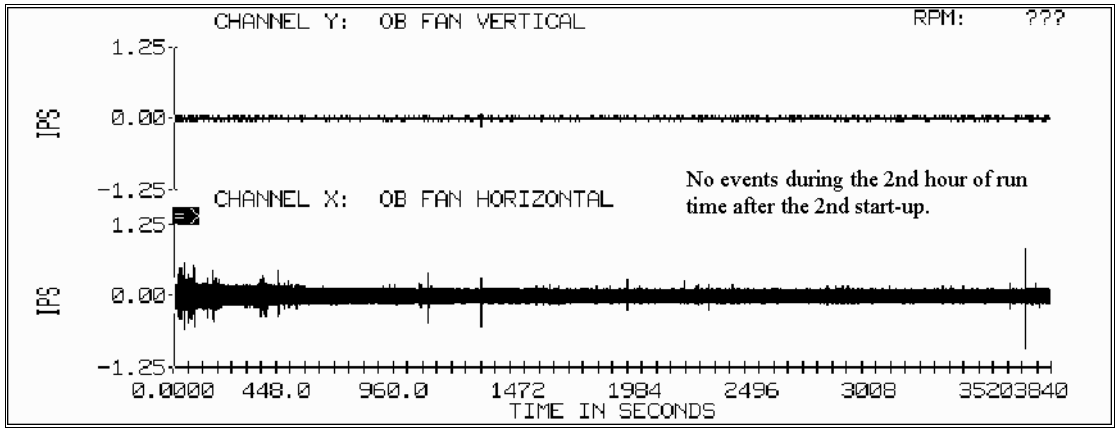

Figure 5 - Time Capture Showing no Events during the second hour after the 2nd start-up (outboard fan bearing - horizontal direction - IPS peak)

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A spectrum analysis (figure 6a and 6b) showed that the predominant vibration frequency was horizontal at shaft turning speed. It increased from .03 IPS to .9 IPS when an event occurred. The horizontal to vertical amplitude ratio on the fan bearing was greater than 6:1 (suggesting resonance.

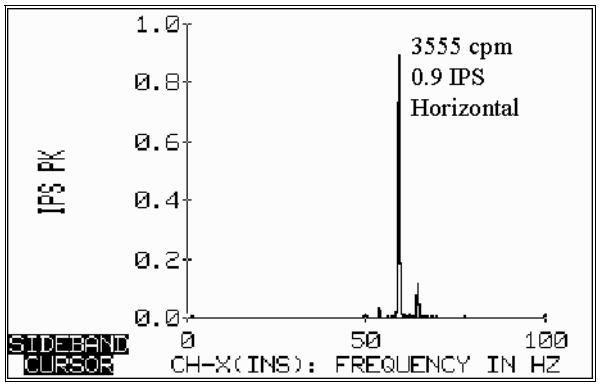

Figure 6A - Spectrum of OB Fan Bearing Horizontal IPS - Peak During Event

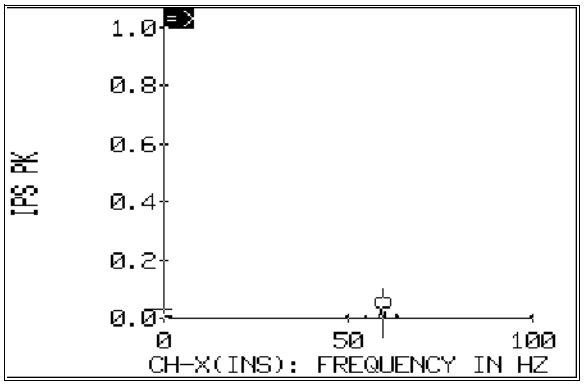

Figure 6B - Spectrum of OB Fan Bearing Horizontal IPS - Peak NO Event

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A shaft vibration and phase study was completed. Table 1 lists the shaft vibration levels and phase at shaft turning speed. The circled velocities represent displacements of 7.4 mils pk-pk (no event) and 25 mils pk-pk (during and event)

TABLE 1
#9 - Q0 Fan -- Vibration at Shaft Speed (3555 cpm)
(Vibration Velocity - Inches Per Second - Peak)

Pos	No Event		During Event	
	Shaft	Phase	Shaft	Phase
1H	0.3	100		
2H	0.9	180	0.9	185
3H	0.5	60	1.2	290
4H	0.4	30		
5H	**1.4 = 7.4 mil**	10	**4.8 = 25 mil**	298
1V	0.2	300		
2V	0.7	100		
3V	0.3	40	0.2	260
4V	0.2	40		
5V	0.4	5	1.8	220

Analysis:

The problem was caused by a condition known as disk skew or rotor wobble (Simplified Handbook of Vibration Analysis - Art Crawford). Fan rotor wobble causes the fan shaft to bend. A wobbling rotor lowers the natural frequency of the rotor into the operating speed range. The intermittent periods of very high vibration occur when the fan rotor is in resonance. Resonance occurs when the amount of wobble increases -- much like a spinning top that wobbles more and more to the point when it looks like it might fall over but then stabilizes its rotation. The wobble problem is caused by couple unbalance or a loose fit between the shaft and fan rotor. The variability of the events on this fan suggests that the vibration is a combination of both looseness and couple unbalance. The shaft-to-rotor fit and amount of couple unbalance are particularly critical on overhung fans with rotational speeds greater than 3600 rpm.

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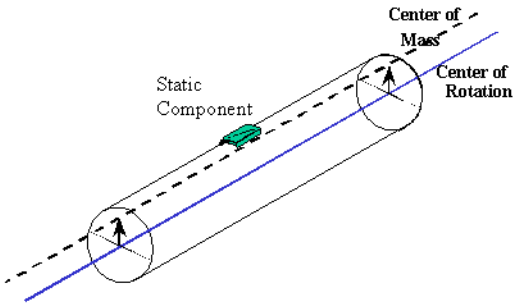
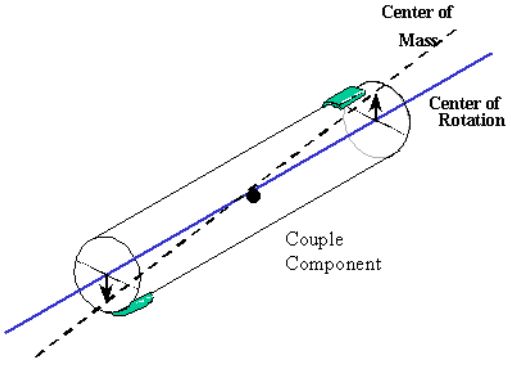
Recommendations

1. Improve the shaft to rotor fit. The mechanics checked the torque of the two bolts that hold the fan rotor onto the tapered shaft. The bolts were torqued to the 70 ft-LB specification. No improvement was gained. This does not mean that the shaft fit is as tight as it needs to be. **There still may be high spots on the shaft and bore allowing the rotor to wobble**.
2. Balance the fan using the shaft readings at positions 2H and 5H. Pay particular attention to reducing both the static and couple balance components.

Static Unbalance - is often called the force unbalance. Static unbalance is the condition where the center of mass is displaced parallel to the center of rotation. A weight, equal in amount and opposite in position to the static component, corrects this type of unbalance.



Couple Unbalance - is the condition of unbalance where the center of mass intersects the center of rotation at the rotor center of gravity. Wobble motion results from couple unbalance. A correction weight must be placed opposite each of the couple components. The correction weights will be equal if the correction radius is the same on each end of the rotor.



Results

Shaft readings at position 2H and 5H were used for balancing the rotor. A static couple, vector, derivation was made from the original horizontal phase and magnitude readings. The "as-found" static component was 0.3 IPS and the couple component was 1.1 IPS - an almost perfect couple with a small amount of static unbalance remaining. Figure 7 shows the "as-found" static-couple derivation vector diagram.

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Note

Readings taken at the fan bearings showed very little static or couple unbalance. The shaft readings were absolutely necessary to balance the fan rotor.

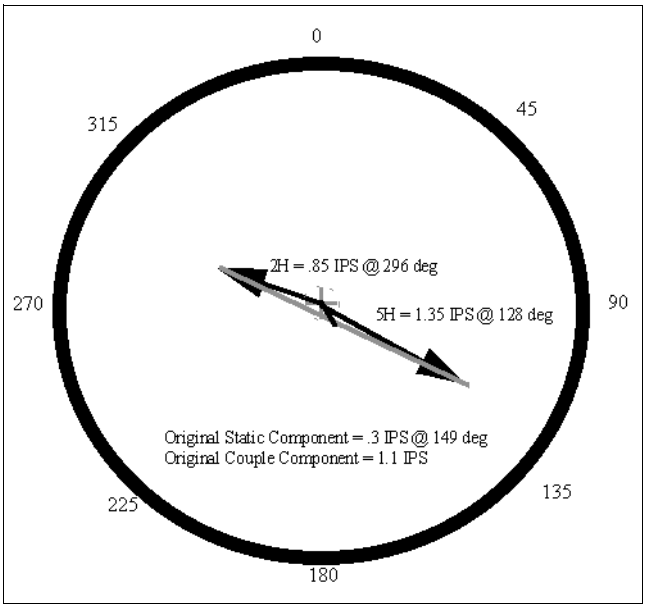

Figure 7 - “As-found” Static couple derivation using shaft readings

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The 0.3 IPS static unbalance was removed using a 5-gram clip-on weight placed at center width of the rotor. The remaining static component was near zero IPS. Figure 8 shows the static-couple vector diagram with all of the static unbalance removed.

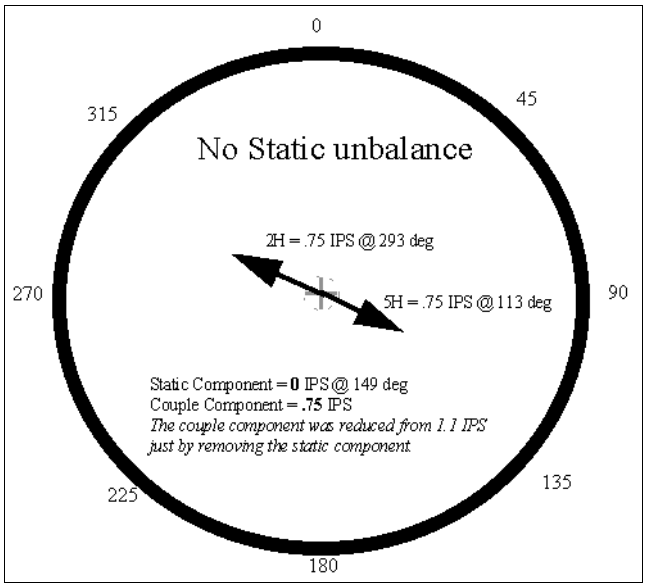

Figure 8 - Static couple derivation after all static unbalance was removed. Only a near perfect couple unbalance remains.

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Finally, the remaining couple unbalance was reduced by adding two 5-gram weights placed at the inner and outer width of the fan rotor at 180 degrees apart. The exact couple weight placement was determined by single plane vectoring the position 5H phase and amplitude, then moving both couple weights the same angular amount. The couple unbalance was reduced from the original 1.1 IPS to 0.16 IPS at position 5H. Position 2 could not be reduced below .65 IPS. There may be some unbalance or misalignment in the coupling. Figure 9 shows the static couple derivation of the final run.

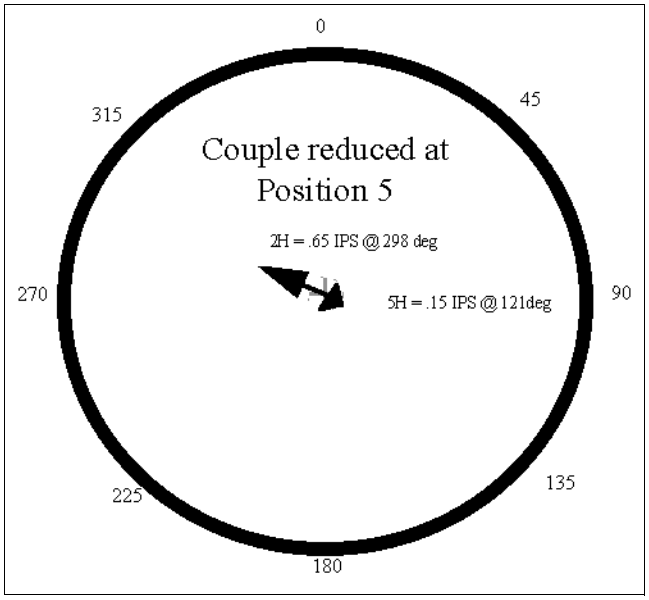

Figure 9 Couple component reduced at position 5. Static couple derivation using shaft readings

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Table 2 shows a comparison of the shaft vibrations on the fan before and after balancing. Note that position 5 is no longer the highest vibration. The only remaining question was would the events continue now that the rotor was balanced?

TABLE 2
Shaft vibration Before and AFter Balance
IPS - peak at 1 x shaft speed (not during an event)

	Before Balance		After Balance	
Position	Horiz.	Vertical	Horiz.	Vertical
1H	0.30	0.20	0.16	0.40
2H	0.90	0.70	0.65	0.49
3H	0.45	0.30	0.41	0.16
4H	0.40	0.20	0.34	0.11
5h	(1.40)	0.40	(0.16)	0.40

A MachineView portable vibration monitor was used to monitor the vibrations on the outboard fan bearing during the night. The monitor was started at about 7pm and measured until 1:15pm the next day. Figure 10 shows that no events occurred. The outboard bearing housing vibration remained below 0.2 IPS.

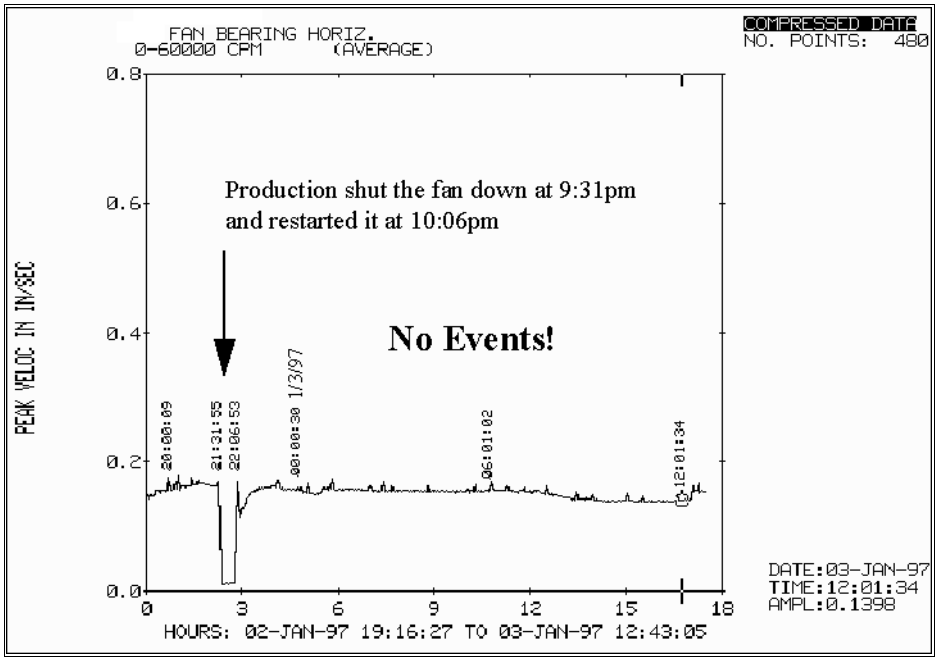

Figure 10 - 17 Hour Trend Fan Vibration - Overall vibration measured on the outboard fan bearing - horizontal (IPS - peak)

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Conclusions

Shaft to rotor fit and multi-plane balance are both critical items on overhung fans rotating at 3600 rpm. It is believed that these problems contributed to the randomly occurring high vibration events on the fan.

The fan balance was improved by using shaft vibration measurements to two plane balance the rotor -- removing the static and couple balance components. The outboard fan shaft vibration was reduced from 1.4 to 0.16 IPS - peak. Reducing the couple forces that caused the rotor to wobble may be enough to keep the fan operating smoothly. No events had occurred during a 17-hour period after the balance was completed

The rotor bolts were torqued and did not appear to be loose. The rotor-to-shaft fit may not be perfect but the problem was solved using transient capture, phase analysis, shaft readings and balancing.

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Case History #5

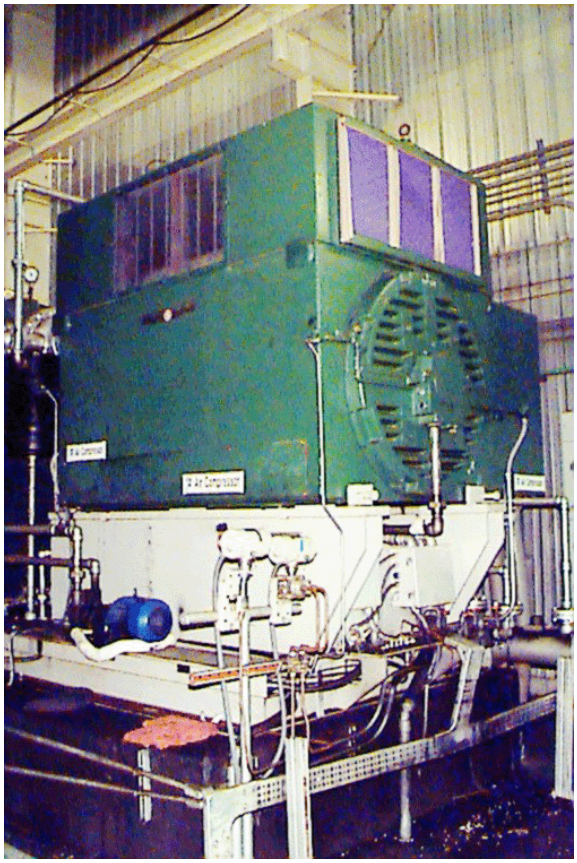
Compressor Motor Vibration

Background

For many years, high vibration levels have been a problem on three 4000 HP, 6900 volt motors driving 5 stage Centac Air Compressors at a Power Plant. The compressors are numbered "A", "B" and "C". Motor speed is 1780 rpm.

Vibrations measured on Compressor "B" motor are the most severe with velocity levels of 0.5 inches per second - peak (IPS - peak) measured on the outboard motor bearing housing. The vibration is highest in the horizontal direction at 2x line frequency (7200 cpm).

Recently, the motor from compressor "B" was sent to a motor repair facility where the motor was completely overhauled. Before returning the motor to the customer, it was tested on the floor of the repair facility. The vibrations were "smooth" (< 0.1 IPS - peak overall vibration). When replaced on its base and operated uncoupled from the compressor, the motor had vibration levels of 0.5 IPS - peak at 7200 cpm. A test for soft-foot on the motor feet had no effect on the vibration levels. Coupling the motor to the compressor did not change the vibration measured on the motor at 7200 cpm.



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All repairs and adjustments made to the motors over the years had not eliminated the vibration at 7200 cpm. Broken rotor bars were found and repaired on two of the three motors. Precision alignments and soft foot checks were made without improvement. The rotor from "B" motor was replaced then later swapped out with the rotor from "A" motor without changing the vibrations.

Problem

Find the source of the 2x line frequency vibration. The concern was for high vibration levels on the motor and the potential for damaging the Centac Compressor.

Equipment Used:

- CSI model 2120-2, 2 channel signal analyzer w/advanced 2-channel and transient capture firmware
- CSI model 404A photo tachometer
- ME Scope Modal and ODS software

Investigation:

Much of the testing was completed on the "B" compressor motor. All measurements made on the "B" motor were under no-load conditions with the motor uncoupled from the compressor. Some tests were repeated on the "C" compressor motor while it was operating at normal load.

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Test 1 -- Vibration Data on compressor "C"

Compressor "C" was on-line when the measurements were made. The predominant vibration on compressor "C" was in the horizontal direction on the motor bearings. The highest velocity was 0.2 IPS - peak at 7200 cpm (2x line frequency) on the outboard motor bearing (horizontal direction). Vibration on the vertical position of the same bearing was less than 0.01 IPS - peak (a 20:1 ratio). Vibrations at turning speed (1789 cpm) were very smooth. Low level sidebands equal to four times slip speed could be seen around every peak in the spectrum. Figure 2 shows a high resolution spectrum of the outboard motor bearing on "C" compressor.

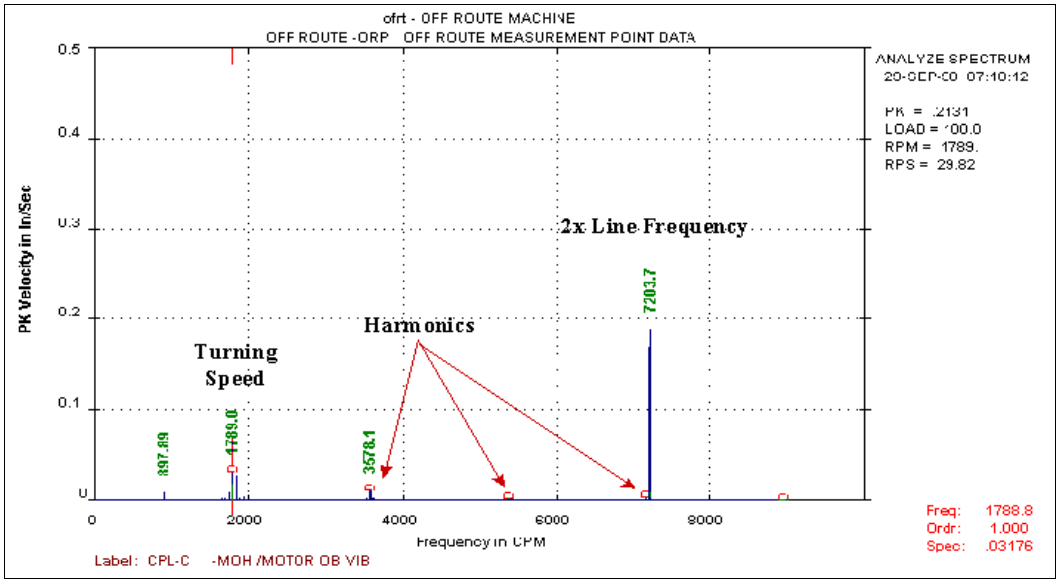

Figure 2 - Spectrum of Compressor “C” - Outboard Motor Horizontal

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It is clear from this high resolution data that the vibration at 7200 cpm is not a harmonic of turning speed. It is twice line frequency. The vibration at 7200 cpm indicates an electrical problem with the motor. Most electrical vibrations occurring at 2x line frequency are related to problems with the stator. The sidebands equal to 4x slip speed also indicate electrical defects. A small peak at 897 cpm is not related to compressor "C" operation. Figure 3 is an expanded view of the sideband content around turning speed of the motor.

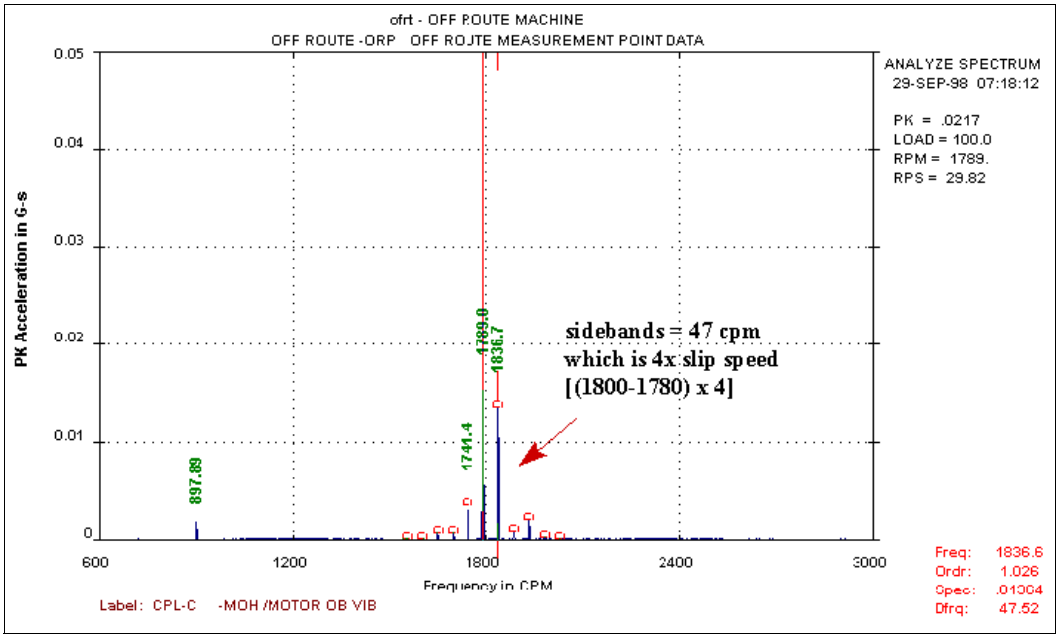

Figure 3 - Zoom Spectrum of Compressor “C” - Outboard Motor Horizontal - 1x and Sidebands

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Test 2 -- Vibration Data on Compressor "B"

Compressor "B" motor was uncoupled from the Centac compressor during testing. The predominant vibration on compressor "B" was in the horizontal direction on the motor bearings. The highest velocity was 0.45 IPS - peak at 7200 cpm on the outboard motor bearing (horizontal direction). The vibration level on the vertical position of the same bearing was less than 0.04 IPS - peak (one tenth the horizontal vibration). Vibrations at turning speed were very smooth. Since the motor was not loaded, there was very little slip. The fourth harmonic of turning speed could not be distinguished from 2x line frequency. Coast down testing later proved that vibration is electrical in nature (just like on compressor "C" motor). The small peak at 897 cpm is not related to compressor "B" operation. Figure 4 shows a high resolution spectrum of the outboard motor bearing on "B" compressor.

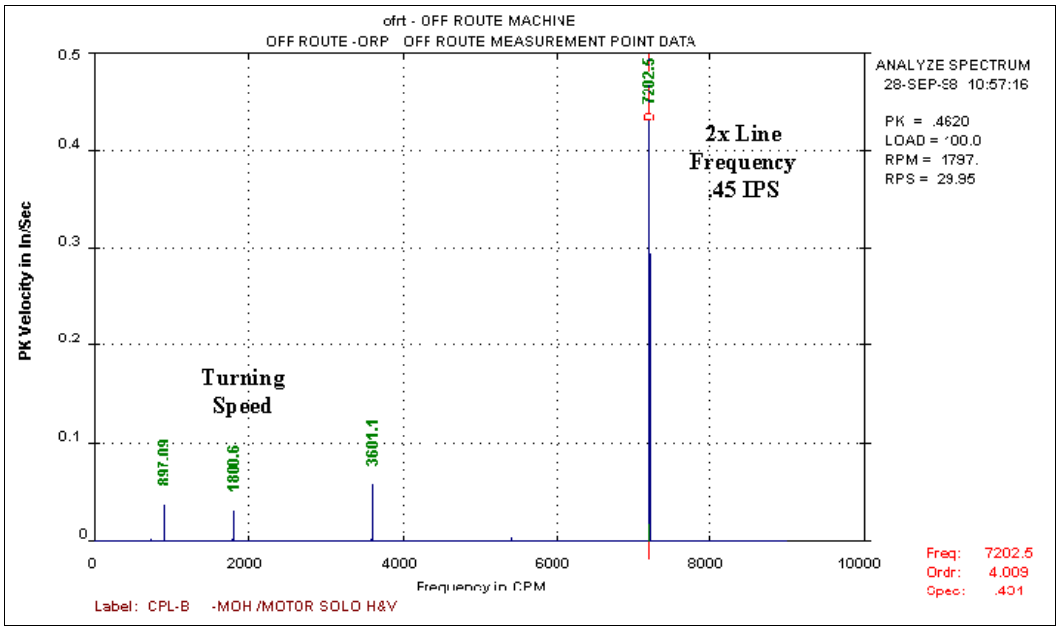

Figure 4 - Spectrum of Compressor “B” (unloaded) - Outbaord Motor Horizontal

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Test 3 -- Shaft Vibration Data on Compressor "B"

A shaft stick was used to measure shaft vibration at the coupling end of the motor. Horizontal shaft vibration was measured simultaneously with horizontal housing vibration. A similar measurement was made in the vertical direction. The data showed the shaft vibration levels were double that measured on the housing. The horizontal shaft vibration was 0.8 IPS at 7200 cpm. The shaft and housing measurements were in phase at 7200 cpm.

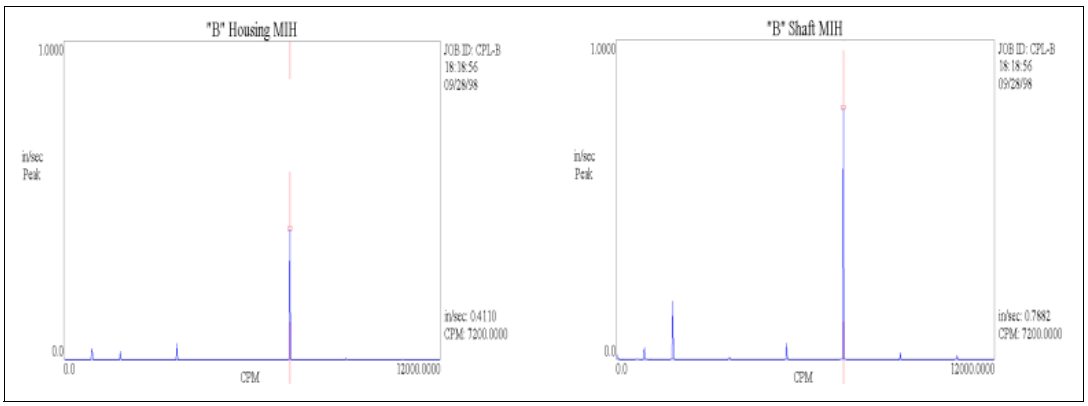

Figure 5 - Compressor “B” Motor - Housing and Shaft Vibration

Test 4 -- Peak Hold Coast-down Data on Compressor "B"

Peak hold coast-down data showed that the vibration at 7200 cpm disappeared immediately when power to the motor was shut off. This is an indication of resonance or electrical sources of vibration.

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Test 5 - Transient Capture Coast-down Vibration Data on Compressor "B"

Like the peak hold coast-down test, transient captured data of a coast-down also showed just how quickly the vibrations at 7200 cpm disappear when power is shut off. Figure 6a shows a 90 second time trace of vibration data on the outboard motor bearing. Just as power is shut off, the vibration goes away completely. Figure 6b shows a peak hold averaged spectrum of the time captured coast-down.

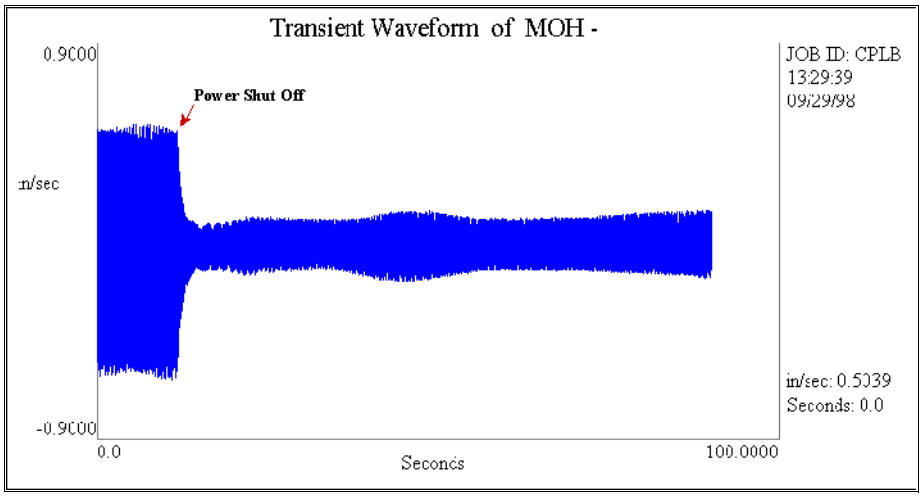

Figure 6a - Time Capture of Compressor “B” - Outboard Motor Horizontal

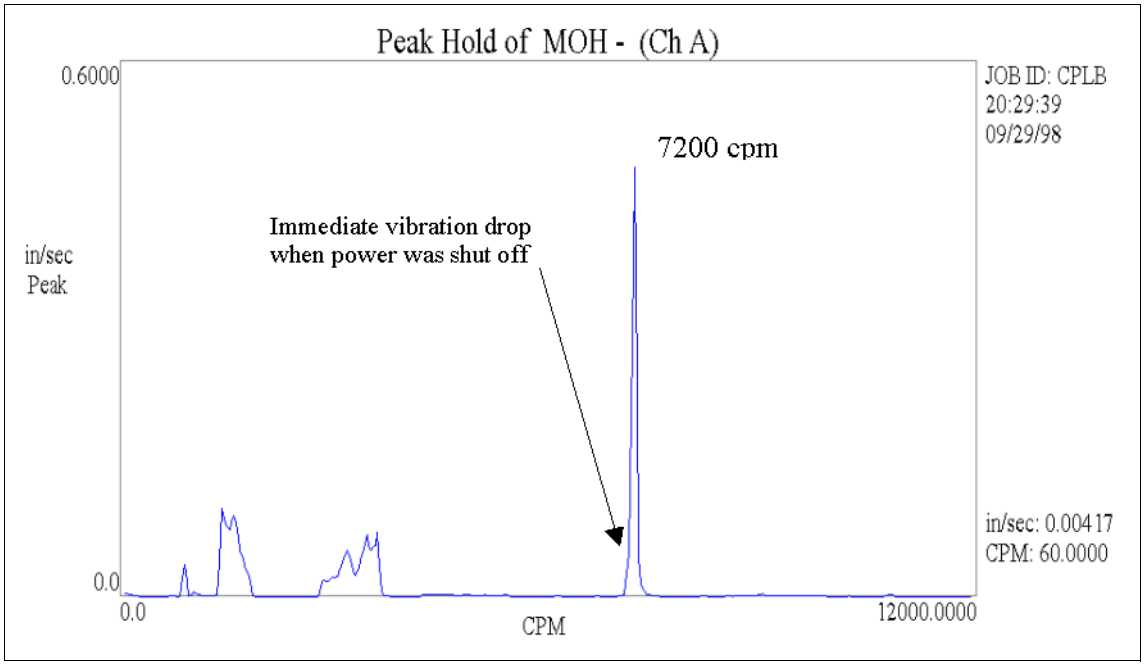

Figure 6b - Peak Hold Coast-down of Compressor “B” - Outboard Motor Horizontal

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Test 6 - Operational Deflection Shape (ODS) on Compressor "B" Motor

Operational deflection shapes show the shape of components during normal operation. Phase and magnitude measurements are made at points on the structure relative to one fixed single axis sensor. The data from this test were imported into ME Scope software where the animations were calculated.

The animation shape at 7200 cpm shows the motor housing bending at its center. The ends of the motor are moving in phase with each other and 180o out of phase with the middle. The support rails underneath the motor are deflecting slightly but not as much at the center of the motor. If viewing an electronic copy of this document, double click the AVI icon to play the ODS animation.

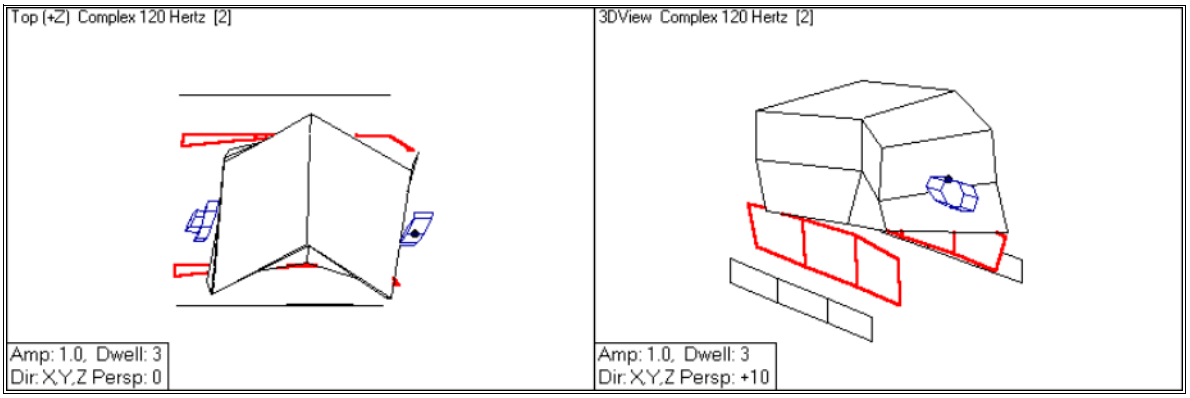

Figure 6b - ODS Animation of Compressor “B” Motor and Support Structure

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Test 7 -- Modal Analysis on Compressor "B" Motor

Modal analysis is the process of characterizing the dynamic properties of a structure in terms of its modes of vibration. In a modal test, the motor is off-line. A modal analysis was completed on the motor housing and bearings, support rails under the motor and the I-beam base frame. A three pound impact hammer, with a medium hardness rubber tip, was connected to the 2120-2's "A" channel and used to impact the motor housing. An accelerometer measured the response data at each point identified in figure 7. The frequency response functions were imported into ME Scope modal analysis software where mode shapes were calculated.

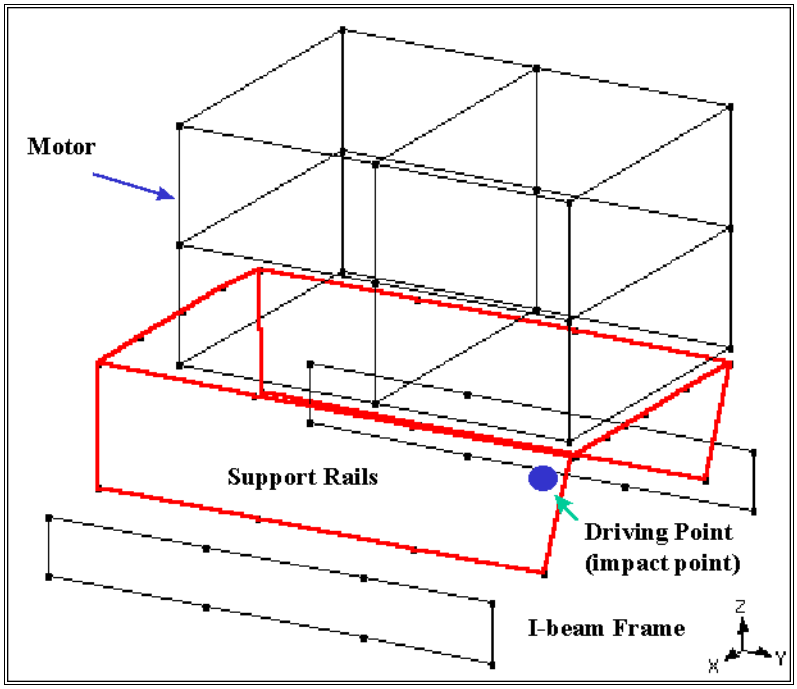

Figure 7 - Modal Analysis Point Layout - Compressor “B”

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The modal results found a natural frequency of the motor at 7600 cpm. The animation shape looks identical to the ODS results at 7200 cpm - the motor is bending at its center. The exciting force causing resonance is electrical vibration at 7200 cpm (2x line frequency). The motor shop did not indicate any electrical defects and the motor shop vibration data was very low amplitude. Figure 8 shows a picture of the mode shape at 7600 cpm.

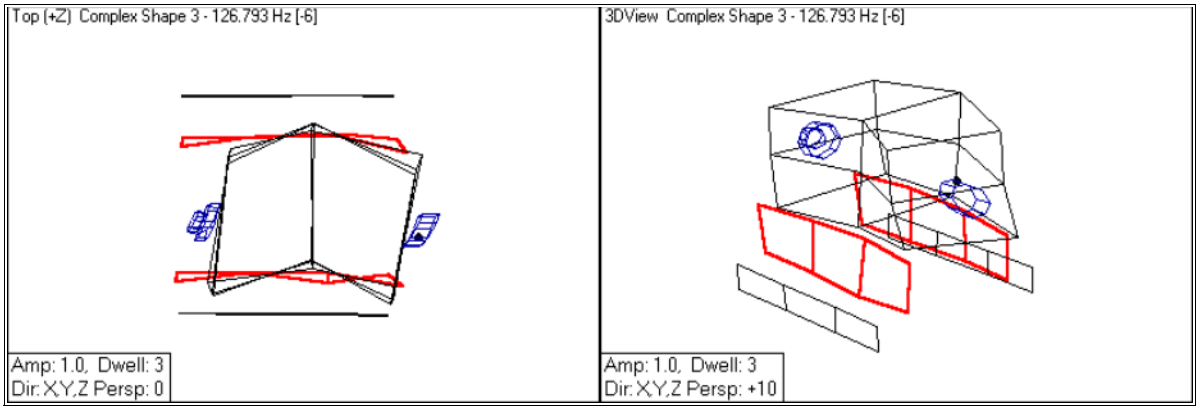
Top (+Z) Complex Shape 3 - 126.793 Hz [-6]
Amp: 1.0, Dwell: 3
Dir: X,Y,Z Persp: 0
3DView Complex Shape 3 - 126.793 Hz [-6]
Amp: 1.0, Dwell: 3
Dir: X,Y,Z Persp: +10

Figure 8 - Mode Shape at 7600 cpm (126.8 Hz) -- Compressor “B”

Test 8 -- Soft Foot Test on "B" Compressor Motor

With the motor operating, the five hold down bolts were loosened (the sixth bolt at the back corner of the motor was missing). The motor vibration did not change. A pry bar was used, unsuccessfully, to try to lift the motor at its corners. The weight of the motor was too great to lift even when a pipe extension was used. The motor had vertical jack screws at the four corners. The screws were adjusted one at a time to lift the motor while at the same time measuring vibration on the motor. An improvement of 0.125 IPS - peak was made. Only three corners were convenient to lift.

Other Testing:

- Flux measurements on "B" and "C" motor (Inconclusive information)
- Negative Averaging bump test on "C" compressor motor while operating (Inconclusive information)
- Motor (side) housing vibrations on "B" and "C" motors (Inconclusive information)

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- Transmissibility between concrete base and I-beam frame (Grout cap is cracked and loose. The original concern was that the natural frequency found was a result of deteriorating grout. This does not appear to be the case. The 7600 cpm vibration is a local mode of the motor housing.
- Current analysis of "B" motor (Inconclusive information)
- Bus voltage comparison (A/B=7063v; B/C=7012v; C/A=7000v. Maximum delta = 63 volts = 0.9% of total).

Summary of test results

A natural frequency was found at 7600 cpm. The machine is resonating at 7200 cpm. Electrical vibration is known to be the force exciting resonance. The motor found no electrical faults on the motor during its last overhaul. In fact, when tested on the motor shop floor, the motor was smooth. The measurement data indicates that the motor may have broken rotor bars.

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What is causing vibration levels of 0.5 IPS at 7200 cpm during operation of Motor "B"?

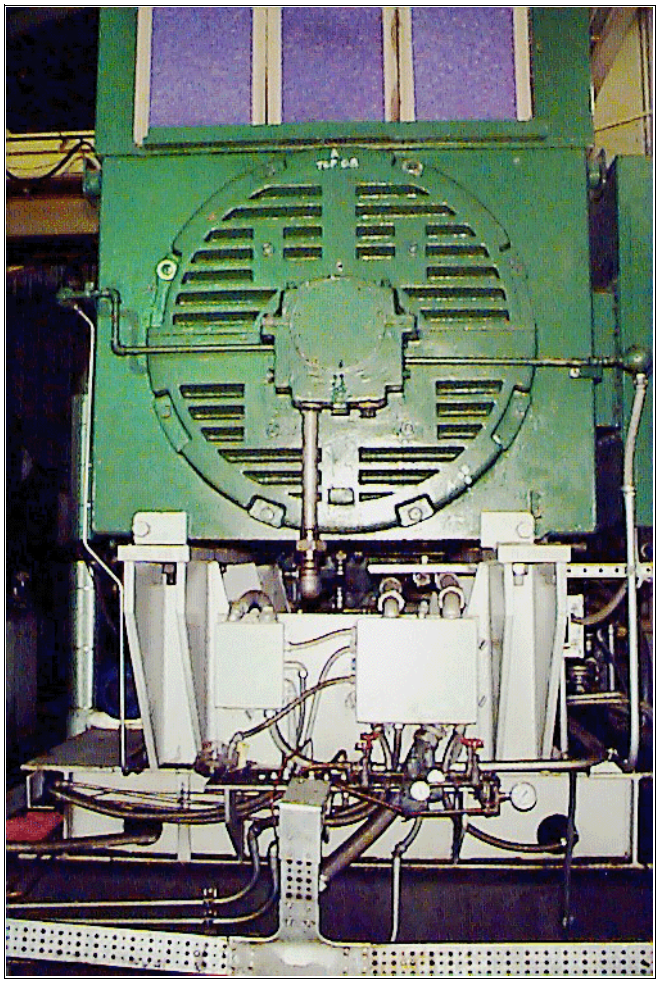

Figure 9 - End View of Motor

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FINAL TEST - Straightness Test on Compressor "B" Motor Support Rails

A string was used to check the straightness of the motor support base rails. The rails were found to be crowned (higher in the center) by about 0.032". The rails were not checked for parallel or skew.

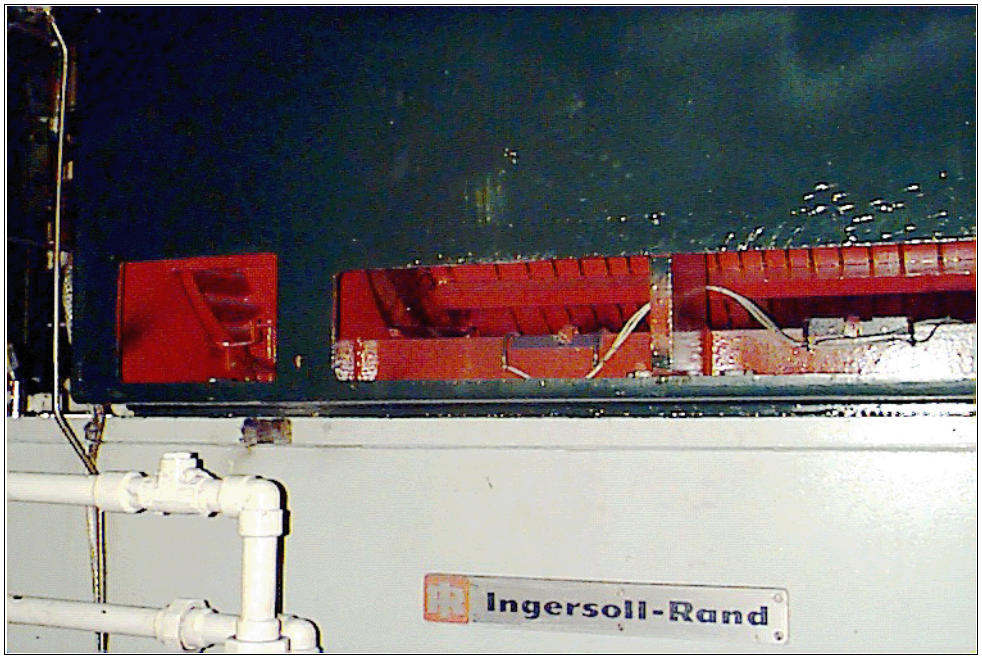

Figure 10 Side View of Motor

Conclusions

The root-cause of the motor vibration problem is a non-flat mounting base. The support rails on which the motor is mounted were checked for flatness and found to be crowned (higher in the center than on the ends) by about 0.032". It is not known if the rails are also non-parallel or skewed.

Due to its welded frame construction, the motor housing is flexible. It is over 7' long and weighs 20,000 pounds. The motor has flat mounting feet that run the full length on each side of the motor. The motor housing must be kept flat and square. Given its flexible construction, the motor housing easily distorts and will conform to the shape of a non-flat mounting Base.

Distortion of the motor housing causes a non-uniform rotor to stator air gap and results in 2x line frequency vibration. Soft foot testing did not show the distortion because of the housing's flexibility.

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The results from the modal analysis identified a natural frequency of the motor housing at 7600 cpm. The electrical vibration at 7200 cpm is only 5% away from this frequency. Since resonance is an amplifier, any small amount of vibration at 7200 cpm results in a large vibration.

Shaft vibration measurements indicated that the motor shaft was vibrating at much higher levels than the housing. The horizontal measurement on the shaft showed 0.8 IPS - peak velocity at 7200 cpm. This level is equivalent to 2 mils displacement peak-peak.

It is reasonable to assume that the broken rotor bars found on two of the motors resulted from vibration stresses on the rotor. Motor "B" may also have broken rotor bars.

Recommendations

The correction required for the "B" motor (and probably "A" and "C" motors also) is to use in-place machining to cut the surface of the mounting rails flat and parallel to each other as well as parallel to the centerline of the compressor shaft. One piece shims are recommended for alignment changes. Given the design of the motor, it is imperative to keep the motor housing flat and square.

Structural modification of the motor housing is not needed. Straightening the motor housing will reduce the force from the electrical vibration at 7200 cpm thus minimizing the effects of resonance.

Results

Compressor "B's" motor base rails were found to be curved and skewed to each other. The base was machined flat and square using in-place machining. The vibration was reduced to a maximum of .15 IPS on compressor "B".

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Case History #6 -- MG Set Misalignment?

Background

The MG Set consists of a Motor/Flywheel/MG Set. All three components are direct coupled and have rolling element bearings. The machine speed is 1797 rpm. Figure 1 shows a picture of the machine.

Figure 1 - MG set (Motor, Flywheel, and Generator)

Overall vibration levels on the MG set have slowly increased since 1997. The vibrations increased from about 0.05 inches per second - peak (IPS) to about 0.3 IPS - peak over the course of two and one half years. The increase began after the flywheel bearings were changed in April 1997. The predominant spectral component was twice rotational speed (59.83 Hz.). The predominant vibration direction has been horizontal on the motor and flywheel bearings. The spectral patterns suggested misalignment.

Various maintenance activities (including laser alignments) were performed over the last 2.5 years. None resulted in acceptable vibration levels. CSI Services was contracted to analyze the machine. One day before the service call, Plant Maintenance completed the following work on the MG Set:

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- Spare motor installed
- New couplings installed
- New flywheel bearings installed
- "super precision" Alignment

When the machine was started, the vibration levels were lower than any point since before 1997. The diagnostic testing that followed the start-up is detailed below.

Problem

The route data indicates that the machine is misaligned. Laser alignment has not corrected the problem. Identify the source of the misalignment.

Equipment Used:

- CSI model 2120-2, signal analyzer w/advanced 2-channel firmware
- MachineView On-Line monitoring system
- ME Scope Modal and ODS software
- Ultraspec 8000 analyzer w/Thermal Growth program and 510 temp sensor
- Three pound impact hammer

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Investigation

1. **Machine Start-up Monitoring** -- A MachineView monitoring system measured vibrations for a period of 18 hours after the start-up. A slight decrease in vibration levels after start-up was noted (figure 2). This decrease is attributed to a slight thermal growth at the motor and generator inboard bearings (see item #4 in this section).

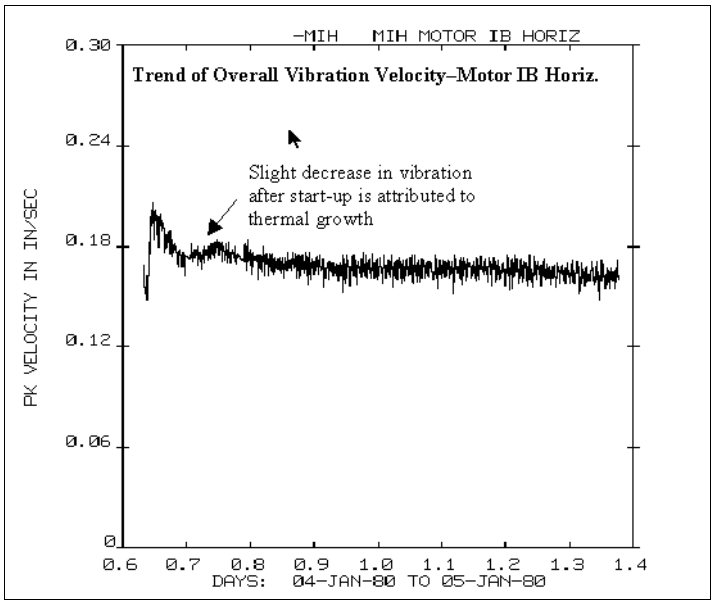

Figure 2 - Vibration Monitoring Trend of Motor IB Horizontal After Start-up

2. **Test for Natural Frequencies** - A test to determine natural frequencies was completed while the machine was off-line. The motor, flywheel and generator were impacted in the horizontal, vertical and axial directions. Since another machine was in operation very close to the MG set, negative averaging testing was used. Negative averaging is a two-part test. In the first part of the test, the machine was impacted. Both ambient vibrations and impact results were present in part one of the test. In part two of the test, only the ambient vibrations were present. Negative Averaging subtracts parts 1 and 2, thus removing the data that was present in both parts of the test and leaving only the impact results. The plot in figure 3 shows the result of the negative averaging test. The data indicates a heavily damped natural frequency at 58.75 Hertz (just below twice turning speed). The natural frequency was localized to the inboard ends of the motor and flywheel. This may explain why previous laser

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alignments have resulted in unacceptable vibration at 2x. Any (small) vibration at 2x is amplified due to resonance)

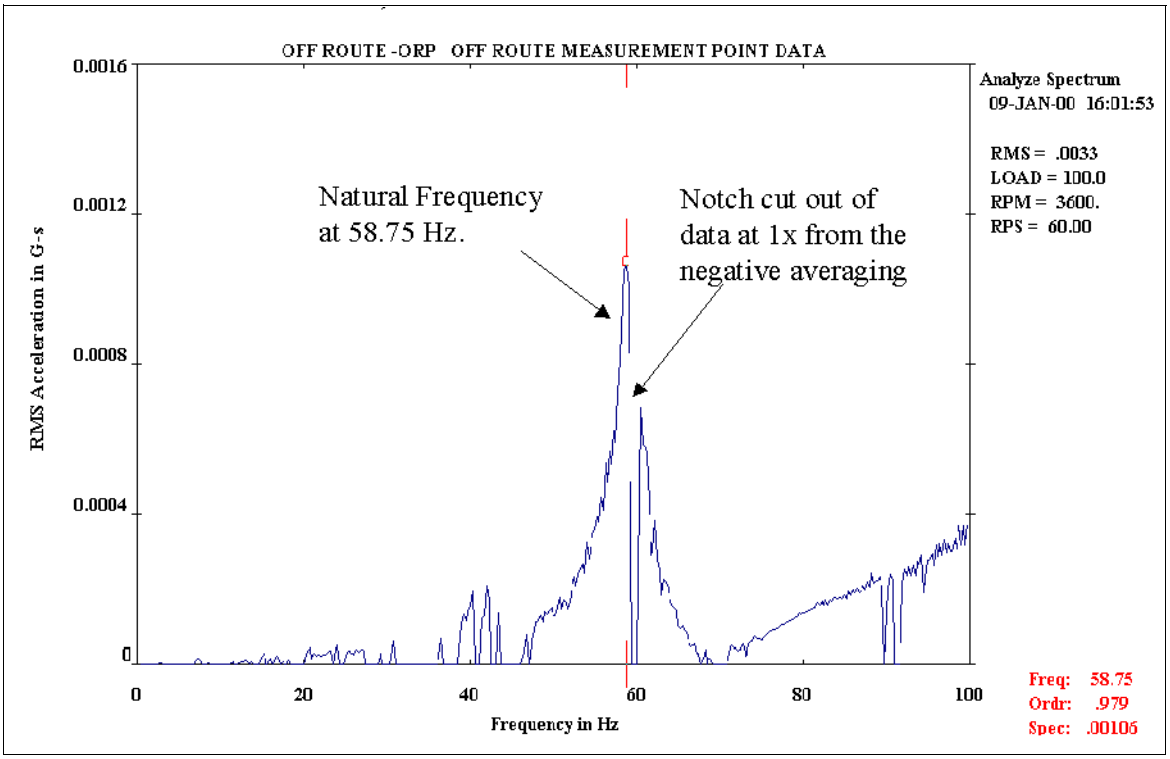

Figure 3 - Result of Negative Averaging Impact Test found a natural frequency at 58.87 Hz

Note

A natural frequency is the frequency at which a part likes to vibrate. Resonate amplifications results whenever forced vibrations from mechanical defects concide with natural frequency. At or near resonance, a small change in the excitation energy produces a significant change in vibration. The amount of amplification depends on the system damping characteristics and the proximity between the natural frequency and the forced vibration.

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3. **ODS** -- Phase and magnitude readings were measured on the floor, sole plates, machine base, machine feet and bearings. The purpose of the ODS test was to show the shape of the vibrating machine during operation and hopefully shed some light on the source of the misalignment. Since the impact testing identified a natural frequency on the machine near twice turning speed, it was thought that the vibration at this frequency might be a result of a "soft" joint. A soft joint between two mating surfaces is created when the connection is not tight. Figure 4a is a sketch of the machine components that were measured. All points were measured in the X, Y and Z directions.

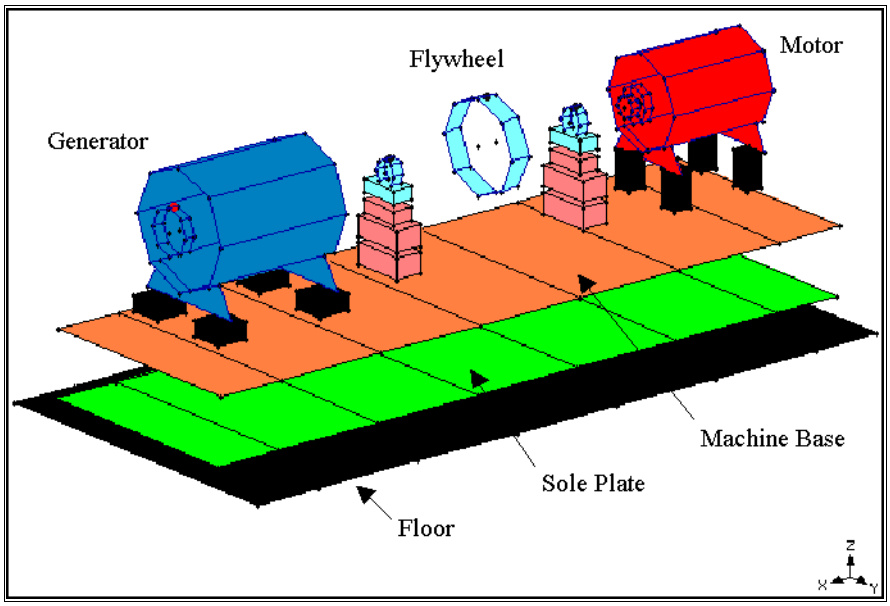

Figure 4a Machine Diagram and Points MEasured in ODS

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The ODS animation showed misalignment between the motor/flywheel and generator. The source of the misalignment appears to be related to a problem with the machine base. A twisting motion of the machine base can be seen in the animation. The twisting motion causes the motor and flywheel to stay in alignment with each other while moving side-to-side and out of phase with the generator. The twisting machine base appears to be a result of a soft-joint condition between the machine base and the sole plate. The sole plate and floor are not twisting. Figure 4b shows a still picture of the machine base twisting. A slight soft-foot condition was identified in one of the generator feet. If reading an electronic copy of this document, double-click the AVI icon to play the ODS animation.

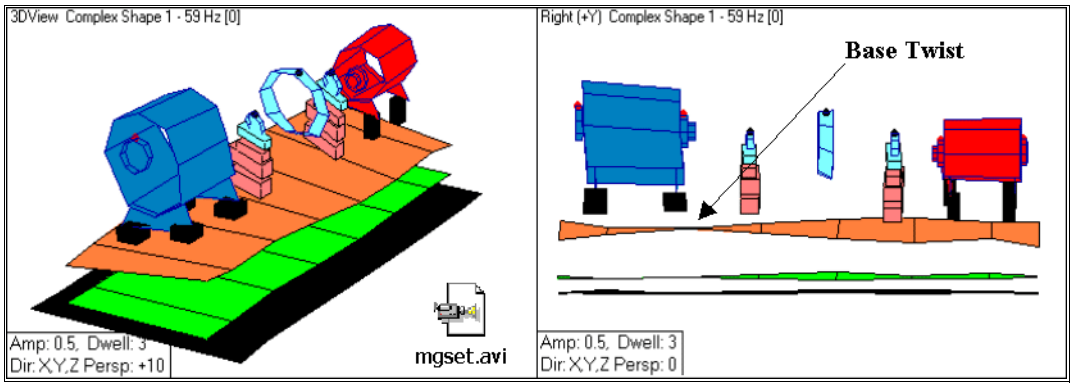
3DView Complex Shape 1 - 59 Hz [0]
Amp: 0.5, Dwell: 3
Dir: X,Y,Z Persp: +10
mgset.avi
Right (+Y) Complex Shape 1 - 59 Hz [0]
Base Twist
Amp: 0.5, Dwell: 3
Dir: X,Y,Z Persp: 0

Figure 4b - ODS Animation Picture at 2x Turning Speed

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4. **Thermal Growth Study** -- A thermal growth study was completed to verify the vertical growth of each component between the off-line (cold) condition and on-line (hot) condition. An UltraSpec 8000 analyzer was used with Thermal Growth firmware and the model 510 infrared temperature sensor. The growth results should be used next time the machine is aligned.

UltraSpec 8000

510 B Temp Probe

Figure 5 shows the net, vertical growth results, in mils, for the MG set (1 mil = 0.001 inch). The thermal growth study indicated that the net vertical growth was 2.0 mils at the inboard end of the generator and 1.0 mil at the inboard end of the motor.

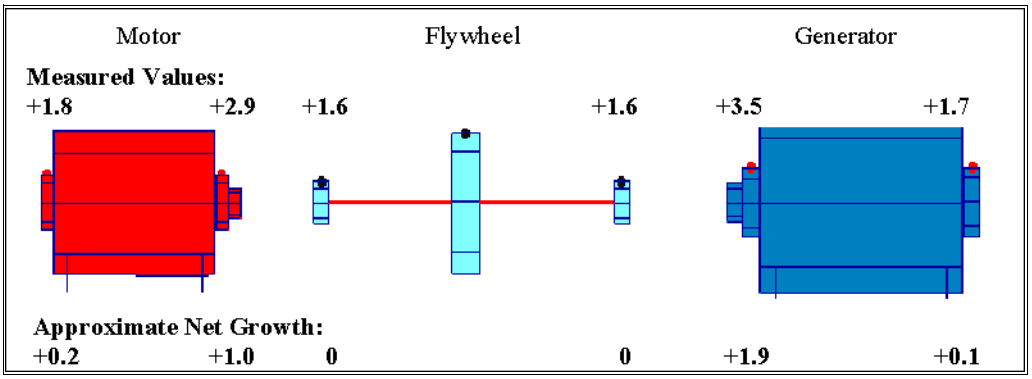

Figure 5 Thermal Growth Study Results

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5. **Bearing Defect Analysis** -- All six bearings were analyzed for defects. PeakVue measurements were made in the vertical direction on each bearing. The PeakVue circuit is sensitive to defects resulting in metal to metal contact and has the ability to find very early stage bearing faults.

Defects were found on the outboard flywheel bearing (generator side). The PeakVue spectrum of the defect in figure 6a clearly shows harmonics of cage frequency (12.53 Hz.) and ball spin frequency (85.17 Hz.). The PeakVue waveform had peak values of 15 g's with a crest factors as high as 9.8. A regular vibration spectrum does not show the defects, however the time waveform shows impacting (figure 6b).

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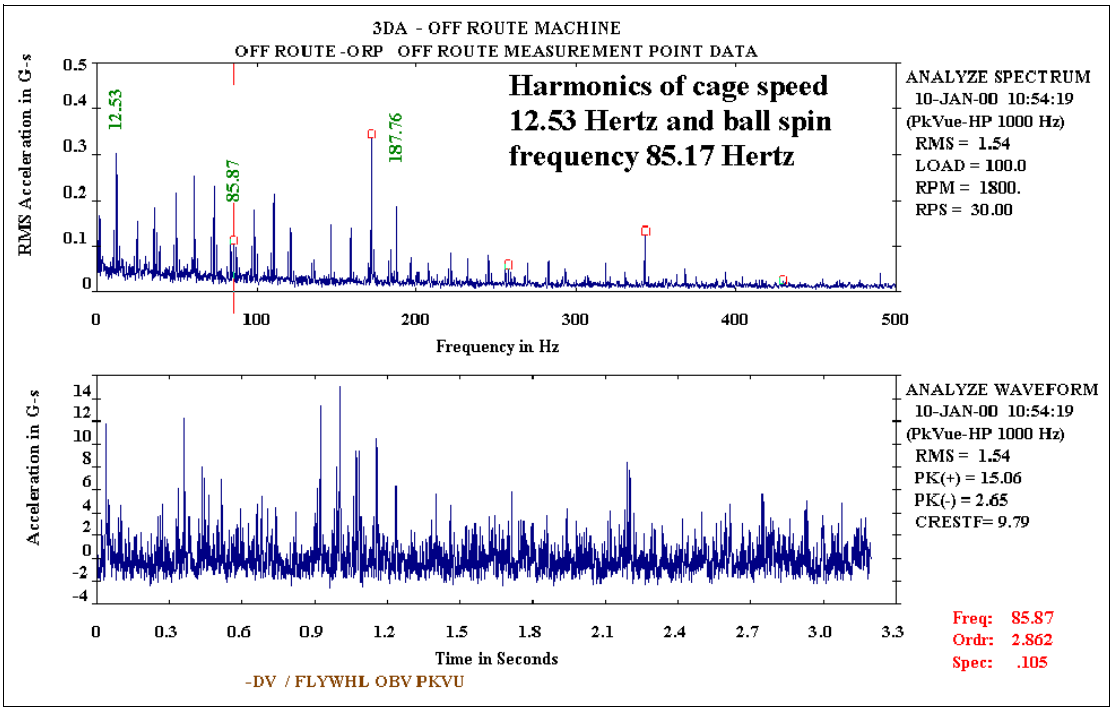

Figure 6a PeakVue Data Shows Defects on the Outboard Flywheel Bearing

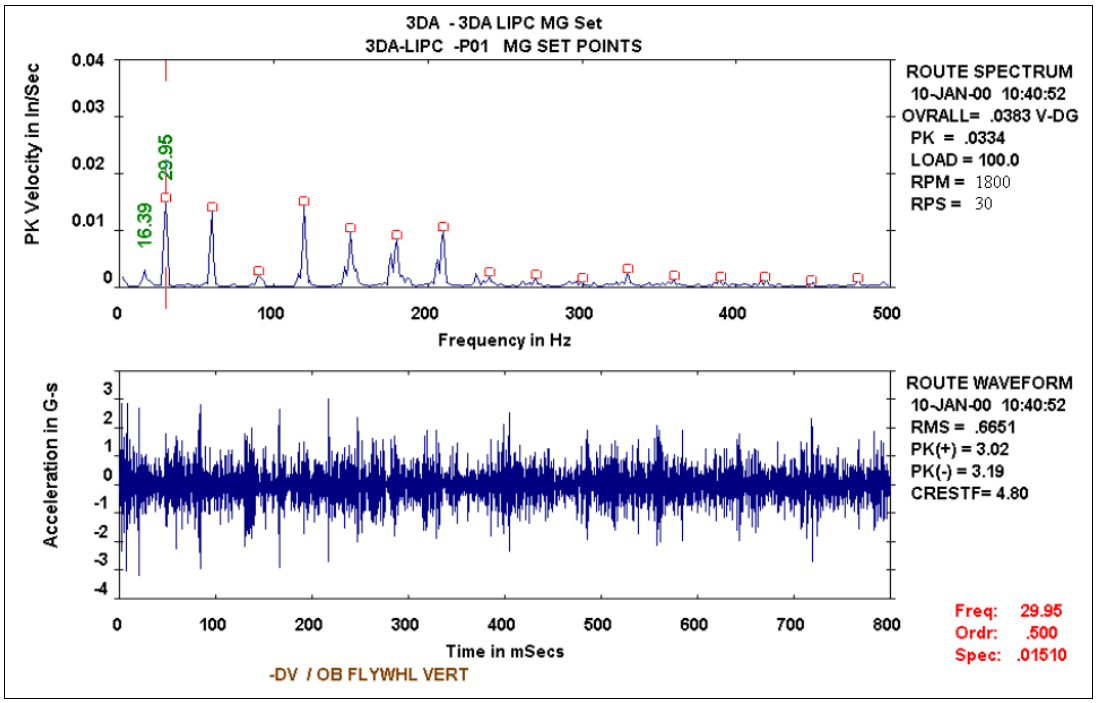

Figure 6b - Regular Vibration Data -- Outboard Flywheel Bearing -- No defect visible in spectrum, Waveform shows impacting

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6. ··**Electrical Defects** -- The motor ha s electrical faults. Although the vibration levels are not exceptionally high, a slight growl could be heard from the motor and sidebands were present around each harmonic. Figure 7 is a vibration measurement made on the side of the motor. It shows motor turning speed and harmonics. Sidebands of 3.56 Hz. were present around each harmonic of motor speed. Two beats can be seen in the time waveform. The first beat is a one-quarter second.

Period = 1 / Frequency
= 1 / 3.56 Hz
= .24 seconds

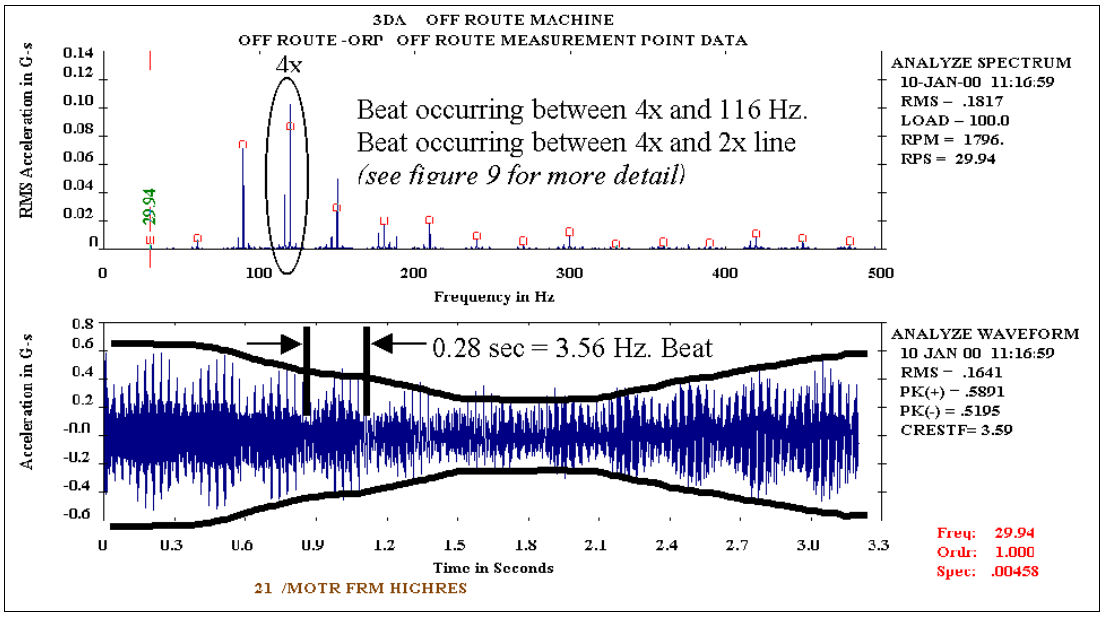

Figure 7 - high Resolution Vibration Spectrum on Motor Frame

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Figures 8 and 9 show high-resolution vibration data, measured at the same position on the motor housing. The peak at 4x is really two peaks - one at 4x turning speed and one at 2x line frequency. The difference between these peaks is 0.22 Hertz and results in a second beat pattern in the time waveform with a 4.5 second period.

Period = 1 / Frequency
= 1 / .22 Hz
= 4.5 seconds

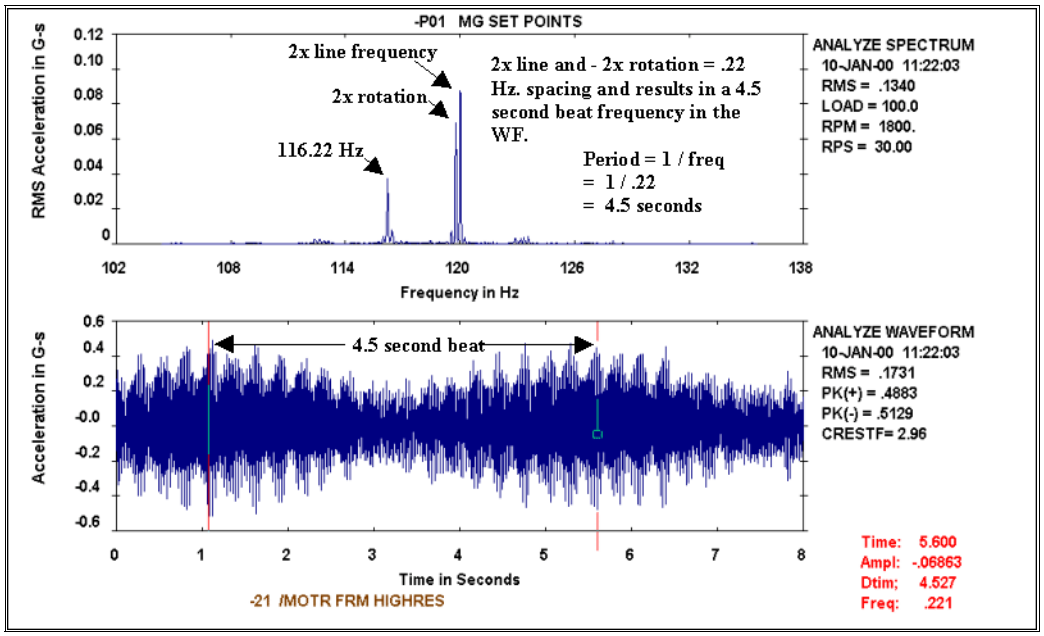

Figure 8 - High Resolution Vibration Spectrum on Motor Frame - 2 x line and 4x speed

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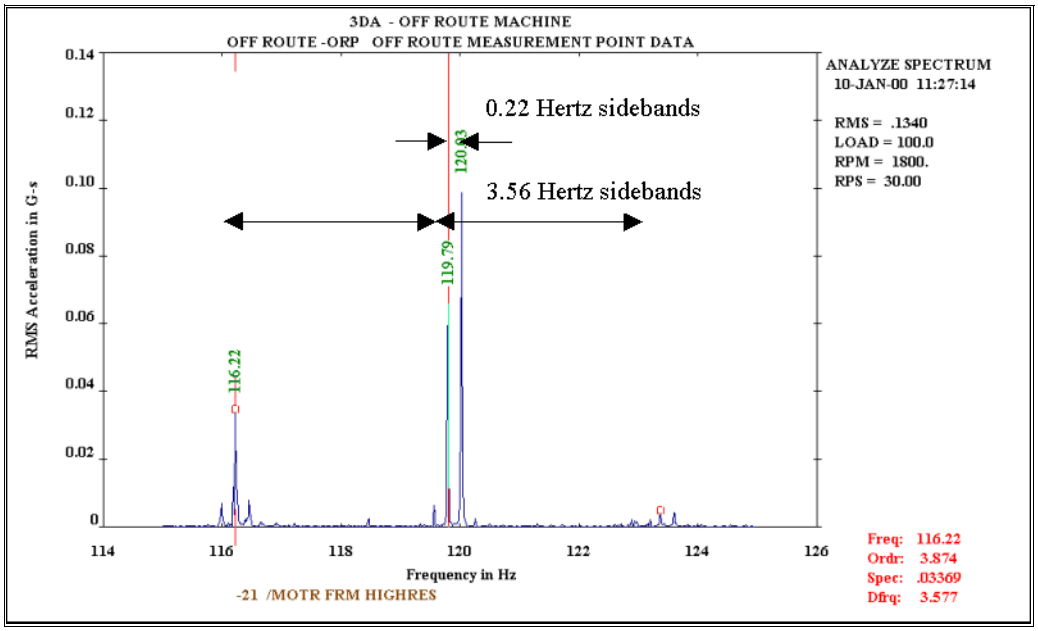

Figure 9 - Motor Frame Vibration Zoom of 120 Hertz

Sidebands of 0.22 Hertz are present around each harmonic of turning speed. Figure 10 shows a plot with log vertical scaling. The 0.22 Hertz sidebands indicate the presence of broken rotor bars. The sideband spacing of 0.22 Hertz is derived from the following equations:

Slip Frequency	*= Magnetic Field Frequency - Rotor Frequency*
	= 30 Hz - 29.945 Hz
	=0.055 Hertz
# Motor Poles	*= (2 x Line Frequency) / Magnetic Field Frequency*
	= 120 Hz / 30 Hz
	= 4
Slip Freq. * # Poles	*= (0.055 * 4) = 0.22 Hz Sidebands*

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The 3.56 Hz. sidebands are most likely an indication of multiple broken rotor bars.

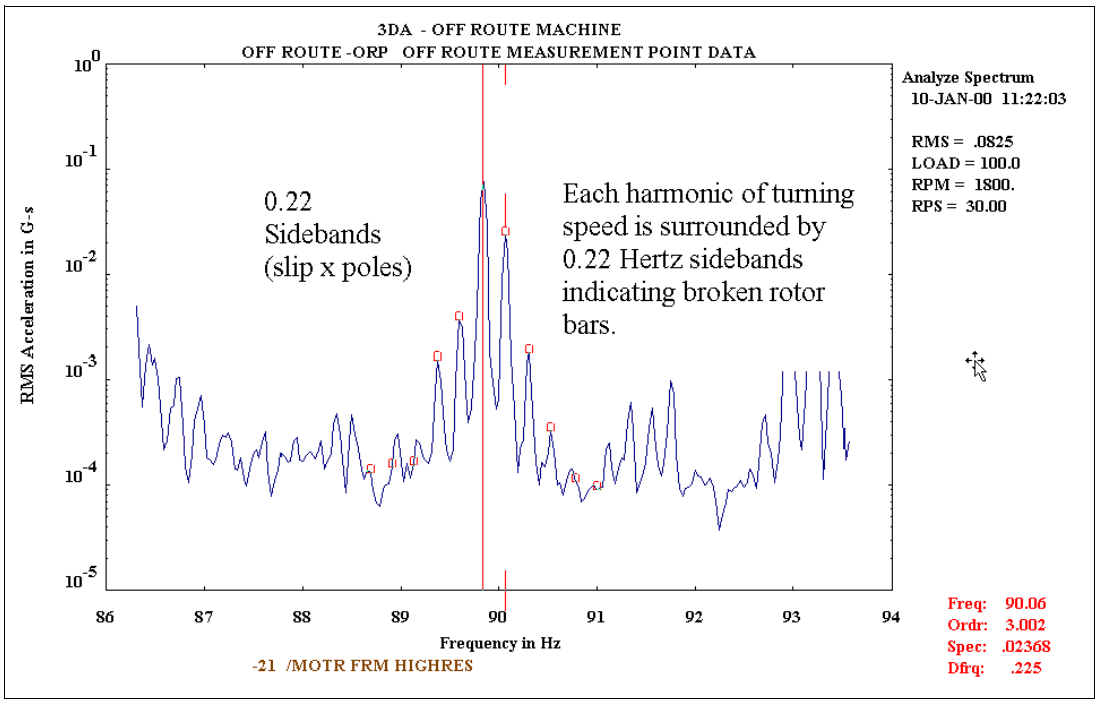

Figure 10 High Resolution of Slip x Poles Sidebands Indicating Broken Rotor Bars

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The slip x poles sideband energy was also evident around synchronous peaks in the PeakVue data taken from the side of the motor housing. The PeakVue plot in figure 11 shows several harmonics of speed. Each harmonic has 0.22 Hertz sidebands clustered around it. The PeakVue circuit is sensitive to metal to metal contacting, however in this case it is measuring the ratcheting effect of the broken rotor bars as it cuts through the lines of flux in the stator. The 3.5 Hz. Sidebands are not present in the PeakVue data.

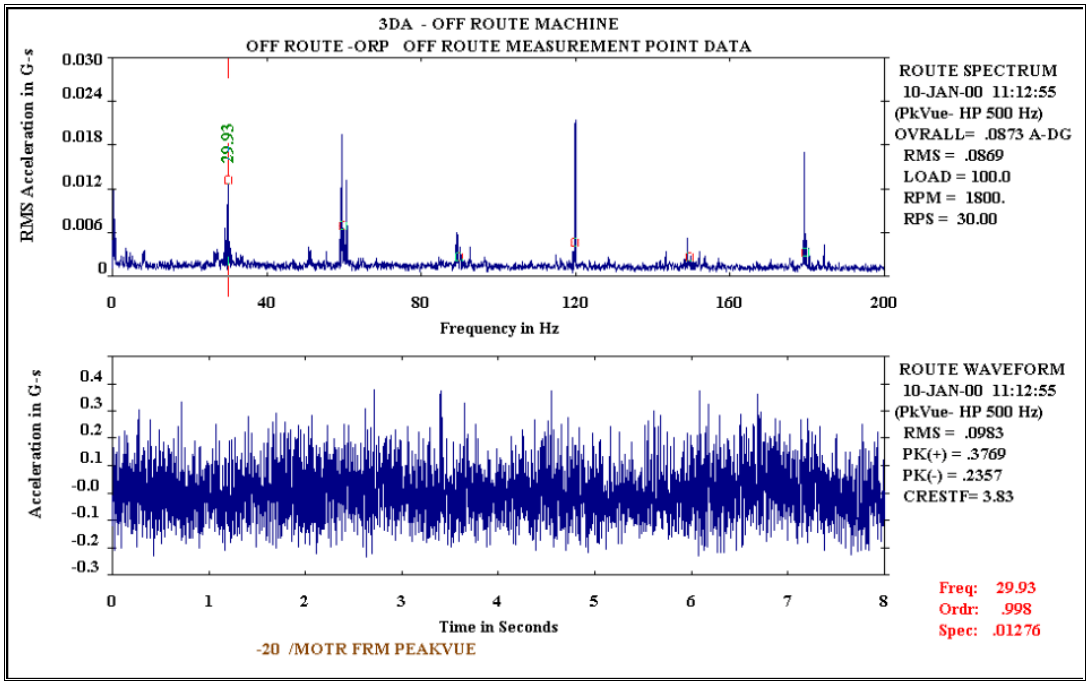

Figure 11 - PeakVue Measurement on Motor Frame

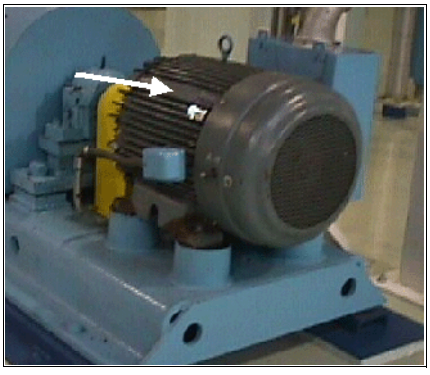

Figure 12 - Location of PeakVue Measurement on Motor Frame

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Summary and Recommendations

The MG Set vibration levels improved after the latest start-up and are within tolerance for the plant. The reason for the improvement was a more precise shaft alignment. A summary of the analysis findings is provided below.

1. A natural frequency at 58.75 Hertz was identified at the horizontal positions of the inboard motor and flywheel bearings (bearings "B" and "C"). Any residual vibration at 59.88 Hz. was amplified due to resonance. Previous alignments may have been within tolerance, however the latest alignment was slightly better and reduced the amount of amplification due to resonance. Resonance is a powerful amplifier. It is not unusual for the residual vibrations to be amplified by a factor of 10 or 20 times. A slight reduction in vibration at 2x would significantly reduce the amount of amplification of the 2x peak.

The ODS results indicate that the machine base is twisting. The pivot point is between the flywheel and the generator. The soft condition is between the machine base and sole plate (under the motor/flywheel). The resonance is a result of the soft joint. Other MG sets at the plant do not have resonance problems near twice turning speed.

The ODS animation also shows a slight soft foot condition on the rear feet of the generator.

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The present condition of the machine is acceptable by plant standards. Any small increase in vibration around 59 Hertz will be amplified until the soft base problem has been corrected. To avoid additional problems, repair the soft base condition. Conditions that could cause increased vibrations at 2x include load or temperature variations, alignment changes and increased electrical vibration at 60 Hertz.

Recommendation *- During the next overhaul, check the machine base plate hold-down bolts for proper tightness and soft foot. A dial indicator can be used on the base near each bolt as the bolt is tightened/loosened. Shim out any soft condition found. Also check the generator rear feet for a soft-foot condition.*

2. ·· Vibrations at electrical frequencies were found on the motor. The data indicates that there are broken motor bars on the motor rotor. A problem with the stator may also be present. The question was asked: "Will the motor run for another 100 days with the electrical defect?" Upon review of the data we thought that it would as long as the machine was not stopped and started often.

Recommendation *- Change out the motor at the next maintenance opportunity. Until then, keep the motor operating and avoid starts and stops. Increase the vibration monitoring schedule and watch for change of condition. Apply load only if necessary.*

3. ·· The machine vibration was monitored for almost a full 24-hour period. The vibrations remained at acceptable levels and even decreased slightly during the first hour of run time. A thermal growth study indicated that the inboard motor and inboard generator grow slightly in the vertical direction.

Recommendation *- If the soft base condition is not corrected, future alignments will need to be as accurate as possible to avoid amplification of the 2x peak due to resonance. Accounting for the slight thermal growth could make the difference (no thermal growth compensation is currently used).*

4. ·· A bearing defect was found on the outboard flywheel bearing. PeakVue data indicates a cage and ball problem. The bearing fault is in the early failure stage.

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Recommendation *- Increase the monitoring frequency of this machine. Use PeakVue and trend the results and watch for increased PeakVue levels. PeakVue is a very sensitive detection method for bearing defects.*

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Analytical Troubleshooting

Appendix A

Preparing for Analysis

Gathering as much history and physical information as possible before acquiring and analyzing data proves helpful. Knowing the physical specifications of the machine provides the analyst with the information needed to calculate potential fault frequencies.

Bearing geometry, coupling type, number of gear teeth, and process considerations all play a part in this process. Take the following steps to properly prepare for analysis:

1. Collect machine information.

Collecting the machine information with a form listing all the information you will need provides a great deal of reference information for building a measurement point, as well as a mental picture of the forces and defects that could possibly occur.

2. Determine appropriate measurement points.

Sketch the machine train and define the nomenclature for each of the points. If multiple machines are in question, ensure the point descriptions from one machine to the next are consistent and easily understandable. If monitoring systems are already installed, use them and their point descriptions for ease and faster setup.

CSi means Reliability Training

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3. Calculate potential fault frequencies.

Every rotating or moving machine component has the potential of failing. For this reason, the fault frequencies should be predetermined. The manner in which the fault is expected to fail should also be taken into account. If a bearing's inner race is the fault condition being defined, the analyst must consider the higher frequencies first. Also consider other similar faults such as stator slot pass, rotor bar pass, and gears.

4. Determine alarm criteria.

Setting the alarm criteria for a machine is easier than it sounds. The presence of fault frequencies indicates existing faults. With this in mind, set the alarms without existing faults. If other machines of the same type are accessible, draw comparisons to establish a mean value for energy. Finally, alarms should also consider trends. After setting the initial alarm levels, look at trends with respect to the rate of change between readings.

5. Set priority of potential faults.

Once the potential faults have been identified, establish the occurrence probability for each fault. Then consider the severity of the fault condition. Faults that may not happen frequently may be considerably more serious, therefore, warranting a higher priority. Last of all, consider the difficulty in detecting the fault condition. If the fault is difficult to identify, the priority for the fault should be placed close to the top of the list.

6. Determine possible fault causes.

Most faults have a variety of possible causes. For example, unbalance may be caused by material build up, wear, broken components, etc. After each of the different causes have been identified, prioritize each cause for each fault condition.

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7. Establish preventive actions.

Some preventive actions should be established to eliminate or at least minimize the frequency of occurrence. Balance and alignment problems can be minimized by precision balancing and alignment techniques.

8. Establish information feedback.

After all is said and done, a feedback loop must be established to refine all the information above. Spectral and waveform data, trends, other machine changes, operational speed and load, work and the reasons for the work should all be a part of the feedback loop. The chart on the next page illustrates the feedback loop. Other components and potential faults should also be considered and prioritized.

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Vibration Analysis Flow Chart

Steps to Solving Vibration Problems

To identify the problem causing the machine vibration, ask yourself some questions.

- What part of the machine has the vibration problem?
- How was the vibration measured?
- Were good measurement procedures used?
- Is the data valid?
- Does the vibration problem occur at only certain loads, temperature or power conditions?
- Is the machine also noisy?

The machine geometry should be understood as completely as possible.

- Sketch the entire machine train.
- Identify all the major components: motor, pump, gears, etc.
- Identify specifications on all the bearings in the machine.

Sleeve or antifriction
Type
Number
Bearing geometry

- Determine belt information.

Center-to-center distance
Pulley pitch diameters
Number of belts

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- Couplings.

Gears
Spool length
Lube Practices
Clearances
How Aligned

Disc
How Aligned
End Clearances
Maintenance practices

Bun
How Aligned
Bun Compound
Possible torsional problems

Fluid
How Aligned
Estimate Slippage

- Drives: motors, engines, turbines
- Gears: types and reduction ratios
- Shaft diameters and lengths
- Rotor dimensions and weights
- Other information unique to the machine

Gather available maintenance history and any previous vibration data.

- Has vibration data been collected on this machine before?

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- Has the vibration fault been developing over time, or is it a new problem?
- Determine the last thing done to the machine.
- Talk to the machine operator and get his/her input.

Determine the best points to collect data.

- At the bearings
- In the problem area
- Consider possible resonances
- Consider forcing functions from other machines
- What type of instrumentation will the solution of this vibration problem require?

Tape recorder
Impact data
Non-contact probes
Displacement, velocity, or acceleration probes
Coastdown or startup data
Single or multi-channel data
Reference transducer input
Current transformer
Special averaging methods
Temperature data

Determine as many forcing frequencies as possible before taking data.

- Determine any and all shaft rotational speeds. Most machine defect frequencies are related to a shaft turning speed.
- Bearing fault frequencies - BPFO, BPFI, FTF, and BSF.
- Belt frequencies.
- Gear Mesh frequencies.
- Blade pass frequencies.
- Resonant frequencies.

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Take data.

- Frequency data, at least horizontal, vertical, and axial data at each bearing. It may be helpful to compare normally averaged data with synchronous time averaging to identify synchronous and non-synchronous components.
- Check for beats by watching the instantaneous spectrum or by comparing the peak hold spectrum with the normally averaged spectrum.
- Check the skirt width of the spectral components. Steady state signals collected with a Hanning window will occupy three to four cells. Wide skirt widths indicate the presence of signal modulation, another component very close in frequency, or a component that is varying in frequency during the sample time.
- Do not limit your data collection to the bearing locations. Data at the bearings should be considered the minimum data to be collected. Consider data collection on the machine case, foundation, piping, etc.
- Once data has been collected, break the spectrum into three different regions: sub-synchronous, synchronous, and non-synchronous.

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Sub-synchronous Frequencies

Sub-synchronous frequencies appear below the shaft turning frequency.

Oil Whirl

Occurs at approximately 44 percent of shaft frequency in pressure fed sleeve bearings. The frequency decreases as the shaft speed slows down. The frequency usually drops out at about 75 percent of normal running frequency.

Oil Whip

Occurs when the shaft is running at a turning frequency above the second critical frequency. The oil whirl frequency locks onto the first shaft critical frequency turning into oil whip. The frequency does not drop away until the shaft frequency drops below the second critical frequency.

Rub

Close to 50 percent of shaft frequency and 12, 22, etc., and harmonics.

Antifriction Bearing Loose in Housing

Fifty percent of shaft frequency, but 12, 22, etc., not as noticeable as rub.

Cage or Train Frequency of Antifriction Bearing

Usually indicates advanced stage of bearing failure. Check for outer race fault and its harmonics as well as sidebands at the cage frequency.

Primary Belt Frequency

Check by calculation and look for higher harmonics. Could be caused by belt misalignment, worn sheaves, or defective belts.

Defective Tooth-to-tooth Repeat Frequency

Usually a very low frequency that can be better seen in the time domain. Often referred to as a hunting tooth frequency.

Surge

Usually a high component from 10 percent to 50 percent of rotor frequency. Check differential pressure across the fan or pump. Check the operating point with the best efficiency point on the fan or pump curve.

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Ignition or Fuel Problem on Four-Cycle Recip

Usually accompanied with higher 2 orders.

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Synchronous Frequencies

Frequencies synchronous with the shaft in the bearing where the data is taken. The frequencies are integer multiples of the reference pulse.

Unbalance

One times shaft speed. If any looseness exists in the system, there may be several harmonics of the first order component. Check horizontal and vertical amplitude and phase at each bearing. If horizontal-to- vertical phase shift is approximately 90E on both sides and the phase relationship is similar, then it is unbalance. If the horizontal-to-vertical phase shift is not close to 90E, consider possible pedestal resonance or shaft centerline misalignment.

If the phase relationships side-to-side in both the horizontal and vertical directions are not similar, consider the possibility of misalignment. If the readings indicate an unusually high unbalance, look for a possible resonance, bent shaft, or fault in rotor supports. Use the weight of the rotor in ounces times the vibration amplitude in inches to estimate the unbalance in ounce inches. For example, a 20,000 ounce rotor times an amplitude of 0.005 inches (5 mils) = 100 ounce inches of unbalance.

If the problem is unbalance and impact data can be taken, impact both sides and estimate the pivot point. If this is far outside the bearings, it may not be possible to field balance the rotor. In addition, the impact data will indicate the first critical at each bearing. If this is close to the running frequency, it may be better to consider stiffening the system.

Misalignment

The first effect of shaft misalignment is an increase in the radial load on the bearings. In most cases, the next effect is an increase in the first order of the shaft frequency. As the condition worsens, the second order builds. Check the axial vibration on the bearings on each side of the coupling. If in phase, consider balance or gear coupling lock-up.

Check vertical-to-horizontal data. High horizontal and low vertical may indicate vertical misalignment. Low horizontal and high vertical may indicate horizontal misalignment. If the misalignment is primarily angular, the top-to-bottom and the side-to-side phases on each bearing are normally out of phase.

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Bent Shaft

High first order, if balance is attempted a bent shaft will usually require large correction weights. Check the axial data at both bearings; 180E phase shift is an indication of a bent shaft. If possible, check the shaft with proximity probes or dial indicators (be sure to check low-speed runout).

Check the top-to-bottom and the side-to-side phase on each bearing. If they are out of phase, it is probably a bent shaft. In most cases of a bent shaft, the end-to-end phase readings of either the horizontal or the vertical radial vibration are the same.

Looseness

Look for many harmonics of shaft frequency. Usually the second is almost as high as or higher than the first order. However, the harmonics will be predominantly odd order if it is pure looseness. Any truncated function will produce harmonics in the spectra so that a condition where the time domain waveform is nonsymmetrical will look like looseness. Check the time domain. One or more system resonances may be excited by one or more of these harmonics so that the levels of the harmonics is magnified by the resonant amplification.

Pitch Line Runout on Belt Sheaves

Often confused with unbalance. Check vibration in line with the belt drive. The frequency of the sheave with the runout will usually appear at the other sheave. If the belts are removed and the first order vibration is significantly lower, it is not unbalance, but more likely pitch line runout. The vibration will be at the frequency of the sheave with the pitch line runout.

Cavitation

Look for the first order and higher harmonics up to the number of blades along with very high frequencies. Check the time domain. Cavitation is the implosion of a void or bubble in the intake fluid when it reaches the pressure side of the pump or fan. Because this can be a very steep waveform, it can usually be easily identified in the time domain. It results in many higher harmonics in the frequency domain. Often the blade pass frequency will appear.

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Blade Pass Frequency

The number of blades, etc., times the rotational frequency. Blade pass is always there; however, high levels can indicate system resonances excited by the blade pass component or an arrangement of supports which causes process flow variations in sync with the blade pass frequency.

On axial flow units, the primary blade pass may be reduced by an out-of-pitch or out- of-track blade, but other harmonics will be higher. Check bearings in the axial direction for components from the first order up to the number of blades as a possible indication of this condition.

Gear Mesh Frequency

The number of gear teeth times the frequency of the gear. These can be very high frequency and many times must be measured with an accelerometer. Frequencies as high as 8,000 to 10,000 Hz are not unusual. A magnet base cannot be used to collect this data. Because the levels can be as high as 50 to 150 G's, it may be difficult to use a hand-held probe. The transducer should be stud mounted or glued to the gear box if the levels are above 20 g's. In addition to the gear mesh frequency and its harmonics, the pinion shaft, gear shaft, gear wobble, hobbing ghost, tooth resonance, and entrapped oil frequencies and their harmonics may also be present in the spectra.

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Non-Synchronous Frequencies

These frequencies are higher than the shaft turning speed, but they are not integer multiples of the shaft turning frequency.

Another Component in the Machine

Identify and determine severity. If possible, attempt to simplify the system by disconnecting or shutting down some part of the whole.

One or More System Resonance

When a system is excited by some energy in the machine or in the process, take enough impact data to identify such resonances and their excitation.

Belts

Even though the primary belt frequencies are subsynchronous, multiples of this frequency can be nonsynchronous. The largest components of belt vibration are usually at higher frequencies. In most cases, the highest level is at the primary belt frequency times the number of pulleys over which the belt passes. In multiple belt drives, there may be frequencies from two times the primary belt frequency up to twice the number of belts times the primary belt frequency in the spectrum.

Any of these frequencies may excite a system resonance and cause the vibration level to exceed the acceptable level. Belt alignment, tension, and quality all play a part in the level of vibration from the belt drive. In some cases, it is impossible to reduce the belt vibration to an acceptable level. Replacing the regular V-belts with Grip-Twist or Grip-Link V-Belts usually reduces the vibration level from two to four times.

For high quality drives, it may be necessary to use flat belts, such as the Habasit belt, in order to reduce the vibration to an acceptable level. These belts usually reduce the belt vibration ten times or more.

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Antifriction Bearings

The basic frequencies generated by antifriction bearings are the cage or carrier, the ball spin, the outer race fault, and the inner race fault. One or more of the primary frequencies along their harmonics and their sidebands may appear in the spectra. Because the outer race is always in the load zone, however, the outer race frequency and its harmonics are the most commonly detected.

The bearing fault frequencies can be calculated accurately from the bearing physical data or estimated. Although the major causes of antifriction bearing failure are improper handling, installation, and lubrication, vibration can give a reliable and early indication of bearing failure.

For antifriction bearing analysis, data should be taken as acceleration using the shortest solid path to the load zone of the bearing for the transducer mounting. Carefully examine the spectra for a series of harmonically related peaks which are not synchronous with the shaft in the bearing.

If the actual fault frequency values are not known, check to see if this series of peaks falls near the approximate value. Operating the bearing above the rated load and at higher than recommended shaft speeds will shorten the life of the bearing under the best of conditions.

Electrical

Vibration can be caused by the dress of the conductors in the raceway, loose lamination in a transformer or a motor, broken or cracked rotor bars, open shoring rings, eccentric rotors, eccentric stator, etc. Conductors should be redressed and loose lamination should be readjusted and tightened to reduce the line frequency and the two times line frequency components.

Eccentric stators cause two times line frequency vibration, which is directional to the largest air gap. Magnetic misalignment results in two times line frequency plus the number of poles times the slip frequency sidebands.

Eccentric rotors cause running speed and twice running speed components with the side bands at the number of poles times the slip frequency. Broken or cracked rotor bars or open or shorted rings may cause line frequency and twice line frequency components at the number of poles times the slip frequency. Broken or cracked rotor bars often show up at one times turning speed with sidebands at the number of poles times the slip frequency.

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This defect only shows up under load, so many motor repair shops are unable to determine these faults. One or more of the faulty bars will cause unequal heating in the rotor, which results in a thermal vector so that the balance will only be good for one load condition. Such thermal vectors are very common in motors and generators.

Noise

Chain drives, gears, the process, etc., can be the cause of high noise levels in the system. It is important to separate the noise problem from the vibration problems. In general, noise levels are reduced by sound absorbing materials and vibration levels are reduced by correction.

Often high noise levels do not indicate a serious vibration problem. Noisy gearboxes, for example, may be the result of the gear frequencies exciting natural frequencies in the gearbox cover which in turn radiates the acoustic energy.

Unusual Sources

There are many cases of unusual sources of vibration C foreign material or objects that move inside a rotor, water weeping in airfoil blades, entrapped water in a rotor which turns to steam when the rotor reaches operating temperature, axial clearance used up by thermal expansion, both bearings locked on a shaft, uneven stress caused by dissimilar material, electrical discharge through bearings, etc. Suspect the unusual when the levels are very high, when phase and amplitude readings do not repeat from one run to the next, or when the readings are erratic.

Background Vibration

The background vibration levels should be checked with the machine shut down. Much time has been spent trying to determine the machine cause of a frequency in the spectrum that later turned out to be present in the background and not part of the machine under study. If both the background and the machine vibration are repetitive, the background levels can be removed from the spectrum by linear averaging while the machine is running and negative averaging with the machine shut off.

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Summary

Remember, vibration analysis is not always as simple as we would like it to be. However, when problems are approached logically, recognizing what is known about the machine in question and its history, the solutions to the vibration problems can be found.

Determine the turning speed frequency. Then the frequencies present in the spectrum can be categorized as subsynchronous, synchronous and nonsynchronous energy. Don't give up during the analysis process and remember to think about the possible unusual causes.

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Glossary of Terms

Appendix B

Accelerance

see inertance.

Acceleration

the rate of velocity change of a mechanical system. Usually measured in units of g (or sometimes G) in English units (1 g = 386.4 in/s2 = 32.2 ft/s2); the international standard unit is m/s2, 1 g = 9.806 m/s2.

Acoustics

the study of sound and its interaction with the human hearing mechanism. See also sound intensity and sound pressure.

Admittance

see receptance.

Amplitude

magnitude of a measured signal.

Analog

describes a signal represented by a proportional electrical voltage, current, charge, etc. By association, any device which operates directly on an analog signal is an analog device, for example analog amplifiers and analog filters are used to condition analog signals at the front end of a digital signal analyzer.

CSI means Reliability Training

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Analog Integration

converting an analog signal representing one parameter into an analog signal representing a different parameter by using analog electronics. For example, an analog signal representing acceleration can be analog integrated once to get an analog signal which represents velocity, or integrated twice to get an analog signal that represents displacement.

Analog-to-Digital Converter (ADC or A/D converter)

a device for converting an incoming analog signal to a series of discrete digital values by sampling. Described by the number of bits it uses, (e.g., 8 bits or 12 bits), it is a key element in a digital analyzer. The number of bits sets a theoretical upper limit on the analyzer's dynamic range, equivalent to approximately 6 dB per bit.

Anchor

a term used to describe a reference mark used for measuring delta time or for marking sideband intervals in the CSI Model 2400 cursor functions.

Apparent mass

the frequency response function representing force per unit acceleration. Note: only in special cases is this function the inverse of the inertance.

Autocorrelation

a time domain function that compares a signal with delayed copies of itself, using all possible time delays, and shows at which time delays the signal repeats itself (periodicities). Although it has seen some applications in characterizing signals buried in noise, usually more information is found in the frequency spectrum of the autocorrelation which is the autospectrum (or power spectrum). Autocorrelation is a special case of cross correlation.

Autoranging

the process of automatically adjusting the input gain of an analyzer to match the amplitude of a signal. Optimizes the use of the dynamic range of the analyzer and improves signal-to-noise ratio.

Autospectrum

another term for the averaged power spectrum of a signal. It has magnitude only, phase information being effectively discarded during processing.

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Averaging

a process of summing a number of time waveforms, sample by sample, or a number of spectra, frequency by frequency, to obtain a better estimate of the mean properties of a signal in the presence of noise or other interfering signals. May be carried out in a number of ways, with or without weighting, including linear (power), negative linear, exponential, peak hold, and synchronous, linear vector types.

A-Weighting

a frequency spectrum shaping applied to frequency spectra in acoustics. The effect is designed to approximate the way that the human ear perceives the loudness of sound. Sound levels are reduced at low frequencies and at very high frequencies, where the ear is less sensitive. There are national and international standards for A-weighting.

Bandwidth

(a) the overall frequency range of an analyzer, e.g. 0 to 1000 Hz; (b) the frequency range over which a filter passes a signal without attenuation; (c) the effective frequency range represented by one line in an FFT spectrum.

Baseband

the frequency range from the low-frequency cutoff to the maximum analysis frequency for an FFT analysis.

Baud Rate

unit of speed for data transmission over a serial communications link.

Bod Plot

in general, a dual plot of both the phase and magnitude information in a signal as a function of frequency. Often used in a more specialized way to describe the plots of synchronous amplitude and phase as functions of synchronous frequency for a machinery spinup or coastdown.

Coherence

a function of frequency which describes the degree of linear relationship between two signals. Used to assess cross-channel measurement quality, locate noise sources, and to check out transmission paths.

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Compliance

or Dynamic Compliance: see receptance.

Correlation

see autocorrelation and cross correlation.

CPM

cycles per minute. Favored by many in machine vibration analysis since the vibration caused by unbalance shows up at a frequency in CPM equal to the RPM of the shaft. Sixty cycles per minute (CPM) is equivalent to one cycle per second which equals one hertz.

Cross correlation

a time domain function that compares two signals using all possible time delays and shows at which time delays the two signals are strongly related. Although it has applications in transmission path analysis and system identification, usually more information is found in the frequency spectrum of the cross correlation, which is the cross spectrum.

Cross spectrum

the basic cross-channel measurement. Used most in calculating other functions such as the Transfer Function, Frequency Response Function and Coherence. Its magnitude measures how strongly two signals are related, frequency by frequency; its phase measures the phase shift between two signals, frequency by frequency. Whether the cross spectrum is from A to B or from B to A depends on whether the phase of channel B is referenced to channel A or the phase of channel A is referenced to channel B. Both forms have the same magnitude, but their phases are equal and opposite. Sometimes called the cross-power spectrum.

Cursor

a manually controlled marker that can be moved across a plot to indicate the amplitude at each time or frequency. See also harmonic and sideband marker.

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Decibels (dB)

a logarithmic system of non-dimensional units that measures the size of a quantity relative to a reference level. Any quantity can be measured in this way, as can any two quantities with the same dimensions be compared using decibel measure. Given a reference power (amplitude squared) level Wref, any other power quantity W, having the same dimensions, may be expressed in decibels using the formula:

dB = 10 log10 (W / Wref)

If a quantity X is in RMS amplitude units, and Xref is a suitable reference level, the formula may be rewritten using W = X2, to give:

dB = 20 log10 (X / Xref)

Digital

describes a signal whose level is represented by a discrete series of numbers, in a format suitable for processing by a digital computer. The representation may be in the form of a waveform or a spectrum. By association, any device that operates on a digital signal is a digital device, for example digital filters are used to filter digital signals after conversion from analog to digital form in a digital signal analyzer.

Digital Integration

converting a digital signal representing one parameter into an analog signal representing a different parameter by using digital processing. A (digital) frequency spectrum representing acceleration can be digitally integrated once to get a (digital) frequency spectrum which represents velocity, or integrated twice to get an analog signal which represents displacement. A single digital integration of an FFT spectrum (in RMS, 0-pk or pk-pk amplitude format) is carried out by dividing the magnitude of each spectrum line by the frequency (in radians per second) of the line.

Displacement

the distance that an object moves, especially when vibrating. There are two types of vibrational displacement in common use:

(a) relative displacement: e.g., the movement of a shaft relative to a bearing surface, measured by proximity or eddy current probes.

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(b) absolute displacement: as measured from a doubly integrated acceleration signal, picked up by an accelerometer on the casing of a machine. Units are mils (thousandths of an inch) and microns (millionths of a meter), which may be shown in RMS, 0-Pk or Pk-Pk formats.

Downloadable firmware (software)

refers to firmware (software) for controlling an analyzer that may be transferred to the analyzer from a computer over a computer interface. The Model 2400 has downloadable basic operating firmware, as well as downloadable applications software, including the standard FFT program supplied with every unit.

Dynamic Flexibility

see receptance.

Dynamic Range

the ratio between the largest and the smallest signals that an analyzer can detect when measured at one and the same time. Not to be confused with the input range of an analyzer, which depends on the available gain settings in the analyzer, nor the equivalent range of the A/D converter, which sets a theoretical upper limit. Actual dynamic range depends upon the quality of the analog electronics in the input signal conditioning stages, the number of bits and error level in the A/D converter, the jitter in the sampling clock, effects of quantization, and the accuracy of the computation.

Dynamic Stiffness

the frequency response function representing force per unit displacement. Sometimes known as effective stiffness. Note: only in special cases is this function the inverse of the receptance or compliance.

Exponential

(a) a type of exponentially decaying window applied to transient waveform data to improve its decay rate and minimize leakage in the spectrum; (b) a type of frequency weighting used to give a better measure of the averaged value of a time-varying signal.

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External sampling

using an external sampling clock signal to override the normal internal sampling clock of an analyzer. Usually uses a synchronous signal giving a fixed number of pulses per revolution of a shaft. In this way all FFT frequency components synchronous with the shaft rotation occur exactly at the center of frequency lines and may be measured without leakage using a uniform window. Non-synchronous frequency components will appear to shift in frequency and are likely to be subject to leakage. Absolute frequency information in the spectrum is lost: each line represents frequencies which are some fixed fraction of the rotation frequency of the machine.

FFT

Fast Fourier Transform. An efficient method of computing a frequency spectrum from a sampled signal waveform, especially suitable for digital computers.

Filter

an analog or digital device which removes or attenuates unwanted frequencies in a signal.

Firmware

the software which controls or instructs the basic operating functions of CSI Machinery analyzers. So-called because this type of software is often burned in to the microchips.

Flat Top

a type of time window designed to minimize amplitude errors in the frequency range, at the expense of frequency discrimination. Mostly used for analyzer calibration at a given frequency.

Force/exponential

a window combination used to improve the quality of the analysis for an impact test (or other test with impulsive excitation). The exponential window is applied to the response channel data, to minimize leakage, and the force window to the exciting impulse channel data, to improve the signal-to-noise ratio. A force window is a short rectangular (uniform) window which brackets the impulse and forces all other data points to zero.

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Frequency

number of times an event repeats itself per unit of time. Units are hertz (Hz = cycles per second) or cycles per minute (CPM).

Frequency response function

a spectrum representing the input/output relationship for a system, e.g., the vibratory response of a structure to an exciting force. The frequency response function is computed as a special case of the transfer function.

Fundamental frequency

the first frequency in a series of harmonic frequencies. For example, the orders of shaft turning speed occur at harmonics (integer multiples) of shaft turning speed.

G (or g)

a unit of acceleration, commonly used with the English system of units; 1 g represents the acceleration due to gravity at sea level and is approximately equal to 386.4 in/s2, or 32.2 ft/s2 (9.806 m/s2).

Group velocity

the rate of change of phase with frequency for the cross spectrum of two signals. If the two signals represent two measurement locations, the group velocity can be used to estimate the time of flight of a signal passing between the two points.

Hanning window

a shaping function applied to a time record before the FFT is calculated in order to smooth out end effects and reduce leakage in the spectrum. Usually the default window type to use for analyzing continuous signals because of the compromise between frequency discrimination and leakage suppression. See also Windowing.

Harmonic

an integer multiple of a fundamental frequency.

Harmonic Marker

a marker used to indicate the multiple harmonics in a frequency spectrum.

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Hertz

a unit of frequency equal to cycles per second (CPS), usually abbreviated as Hz. Favored by many in general signal analysis because it is the international (SI) standard frequency unit. One hertz is equivalent to one cycle per second which equals 60 cycles per minute (CPM).

Impact Test

a type of test used to investigate the properties of a structure, in which the structure is caused to vibrate by an impulsive load from an instrumented hammer and the vibratory response is picked up by a vibration transducer.

Impedance

(a) mechanical impedance is the frequency response function representing force per unit velocity. Note: only in special cases is this function the inverse of the mobility; (b) acoustic impedance is a frequency response function relating the sound pressure produced by a sound source (such as a vibrating surface) per unit volume velocity; 8 specific acoustic impedance is a frequency response function representing the sound pressure per unit area of vibrating surface; (d) electrical impedance is the frequency response of an alternating current electrical system, representing the ratio between voltage and current.

Inertance

the frequency response function representing acceleration per unit force. Also known as accelerance.

Instantaneous spectrum

the basic spectrum computed by the FFT process from a single data record. A complex-valued function, it contains information about both magnitude and phase with respect to the start of the time record.

Intensity

a quantity that measures the rate of power flow through a surface per unit area, in a given direction. Usually refers to acoustic or sound intensity, but may also be defined for vibratory power flow. May be measured with FFT analyzers by using two transducers and the cross spectrum.

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Linear

describes a system with special properties that has an output spectrum directly proportional to its input spectrum and that does not generate new frequencies. The constant of proportionality is fixed, but may differ from frequency to frequency. Many systems can be analyzed as if they were linear, at least over restricted parameter ranges.

Linear averaging

a type of averaging in which the mean square magnitude of the instantaneous spectra of a number of time records is computed for each frequency. Also known as power averaging, the averaged spectrum is often expressed in the RMS format.

Linear vector averaging

a type of frequency averaging in which amplitude and phase information in each instantaneous spectrum are used to define a vector and averaged in a vector sense with spectra from other time records. Only meaningful if analysis is triggered, in which case the spectrum is identical to the FFT of the time averaged waveform.

Linear vector spectrum

a spectrum that has both magnitude and phase information, or, equivalently, a complex spectrum. Examples include an instantaneous spectrum, the cross spectrum, and a linear vector averaged spectrum.

Live-Time

a term growing in popularity, generally means showing the waveform and frequency spectrum at the same time as data is being acquired. A live-time display gives a visual impression of how a signal varies with time. Compare with real-time.

Mil

a unit of displacement equal to one thousandth of an inch.

Mobility

the frequency response function representing velocity per unit force.

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Modal Analysi

the process of modeling the modes of structural vibration, including resonance frequencies and damping, by mechanical testing, frequency analysis and computer processing.

Negative linear averaging

a type of averaging that starts from an initial linear averaged spectrum and proceeds to compute a new averaged spectrum by subtracting the contribution of each new data record, instead of adding as in linear averaging. Very useful for subtracting background effects from averaged data.

Nonlinear

describes a system whose output is not proportional to its input.

Nyquist Plot

in general, a polar plot of the real and imaginary parts or magnitude and phase, of a complex spectrum, such as an instantaneous spectrum, a linear vector averaged spectrum or a cross spectrum. The term is also used in a special sense in the analysis of machine spinup or coastdown data to mean a plot of the synchronous magnitude and phase of one of the orders of shaft running speed in a polar format as the synchronous first order frequency changes. At any speed, the magnitude and phase in the Nyquist plot are exactly equal to the magnitude and phase in the corresponding BodJ plot.

Octave band

describes a type of bandpass filter that has a bandwidth equal to 70.7 percent of its center frequency. Conventionally used for analyzing sound levels, there are standardized center frequencies and filter characteristics for such filters. Adjacent octave band filters have center frequencies spaced approximately a factor two (one octave) apart, hence the name. A frequency analysis in terms of octave bands is called an octave (also whole octave or 1/1 octave) analysis. An FFT analyzer can be used to synthesize octave band filters from an FFT spectrum and thereby carry out an octave band analysis, although this is strictly only valid for steady signals.

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One-third octave

like octave band, but for a bandwidth of approximately 23.1 percent. There are three one-third (1/3) octave bands for each octave band. A one-third octave spectrum can be synthesized from one or more high resolution FFT spectra.

Operating Deflection Shape (ODS)

the way that a machine or structure is deforming, or moving, at one or more frequencies under the action of normal operating loads. Use of multichannel analysis greatly simplifies and improves the range and quality of ODS analysis; dedicated ODS or modal analysis software can be used to generate visualizations of the operating deflection shapes.

Order

a multiple of a shaft turning frequency. The first order is the shaft frequency itself, in CPM numerically equal to the machine RPM.

Order Analysis

a frequency analysis in which the frequencies are expressed as orders of shaft frequency, either by normalizing by the shaft frequency, or by using external synchronous sampling.

Order Tracking

a measurement of a signal from a machine whose speed is changing with time, showing the level of one or more orders as a function of machine speed or time.

Overlapped processing

a way of acquiring and processing data when using a Hanning window, in which each successive time record uses part of the previous record. This gives an increase in the rate at which the display can be updated, giving an apparent increase in live-time rate for lower frequency ranges. There is also an improvement in the smoothness of the data and the statistical error is reduced for a given data acquisition time. However, the method is inappropriate when triggering data acquisition and it causes an actual reduction in the real-time rate. An overlap of at least 50 percent (2) is required to gain benefits from smoothing the data, but the smoothest data is achieved for overlaps of 2/3, 3/4, 4/5, 5/6, etc.

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Peak

(a) the overall maximum level of a signal in a given period of time. For sinusoidal (single frequency) signals, the peak level is 1.414 (%2) times the RMS level; for non-sinusoidal (multiple frequency) signals, this is no longer true, and the peak and RMS are not simply unrelated. Abbreviated as pk, 0-p or 0-pk. (b) An isolated maximum in a frequency spectrum, either due to a single-frequency component or the resonance of a system.

> ***Note***
> Peak-to-Peak

(pk-pk, p-p) the difference between the maximum and the minimum levels (positive or negative) in a signal over a given period of time. For a sinusoidal (single frequency) signal, the peak-to-peak level is always two. times the peak level and 2.828 (2%2) times the RMS level. For non-sinusoidal (multiple frequency) signals this is no longer true and there is no simple relationship between peak-peak, peak and RMS levels.

Peak hold

a type of averaging in FFT analysis in which the maximum level is retained for each frequency line over all data records processed.

Period

time required for one complete cycle of a periodic signal.

Periodic signal

an ideal signal that repeats itself exactly after a fixed finite interval of time and exists for all time. Although not possible in the real world signal, many signals behave like periodic signals for a certain length of time, for practical purposes. Fundamental concept behind FFT analysis.

Phase

(a) the relationship between the angular location of the high spot and heavy spot for an unbalanced rotor; (b) the angular relationship between the peak in the vibration at a synchronous frequency and a phase reference (tachometer) pulse, for a rotating machine; (c) the delay between two signals at a given frequency, expressed as a fraction of a cycle, usually in degrees.

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Power averaging

see linear averaging.

Power spectrum

a spectrum of a signal formed as the mean square average level of a number of instantaneous spectra. Often displayed in RMS format, by taking the square root of the mean square level at each frequency.

Power Spectral Density (PSD)

a representation of the power in a signal that compensates for the bandwidth of the analysis. In FFT, PSD is computed from a power spectrum (in units of power = (amplitude)2), by dividing by the bandwidth of each line in hertz. The units of PSD are then (amplitude)2/Hz. Sometimes, an RMS format is used, in which case the units are amplitude)/%Hz.

Pre-/Post Trigger

triggered data acquisition using a delay so that the time record starts before (pre-trigger) or after (post trigger) the trigger event. The Model 2400 can use trigger delays from 8 time record lengths before the trigger to 100 time record lengths after the trigger.

Real-time rate

refers to the frequency at which the time an analyzer takes to compute an FFT is equal to the time required to acquire the data. Commonly used as a measure of the speed of an analyzer and equally commonly confused with the rate at which the display is updated. Overlapped processing reduces the actual real-time rate.

Receptance

the frequency response function representing displacement per unit force. Also known as admittance, (dynamic) compliance, and dynamic flexibility.

Resolution

the frequency range represented by one line of an FFT spectrum. Found by dividing the maximum analysis frequency by the number of lines. The resolution in Hz is equal to the inverse of the data record length in seconds.

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RMS

root mean square; as applied to a dynamic signal such as vibration or sound refers to an averaged level of a function obtained by averaging the square of the signal level over a period of time (or number of data records), then taking the square root of the result.

RS232

a serial, asynchronous communications standard; a type designation for cables used to connect communications ports on a computer with other digital devices such as digital analyzers, printers and modems.

Sideband

a frequency component that represents the effect of modulation on a signal. If a modulated signal has more than one component, each component will show sidebands. A sideband is spaced off from the frequency of the modulated signal by an amount equal to the modulating frequency. If the modulating signal has multiple components or if there is frequency modulation, the sideband pattern may be very complicated including sum and difference frequencies between the sideband component frequencies (intermodulation effects).

Sideband Marker

a marker used to indicate the sidebands around a center frequency marked by setting a mark, then highlighting an adjacent frequency component.

Signal-to-noise ratio

the ratio of the power of the signal to the power of the background noise effects in a measurement, usually expressed in decibels. In a signal analyzer, the signal-to-noise ratio is typically improved by increasing resolution or the number of averages, among other factors.

Software

computer programs for calculating functions or controlling digital devices with a digital computer.

Sound

vibratory movement of the air, or some other conducting fluid, characterized by a compressive wave mechanism with a constant speed of propagation in a homogeneous unrestricted medium.

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Sound Pressure

the pressure exerted by the movement of fluid particles in a sound wave.

Spectrum

the frequency domain representation of a signal. In practical measurements, the spectrum usually displayed as a plot of magnitude against frequency over a limited frequency range. See also cross spectrum, power spectrum and linear vector spectrum.

Synchronous averaging

a type of averaging in which successive time records are averaged together without computing a frequency spectrum. If the analysis is triggered synchronously from a rotating shaft or some other periodic event, the averaged waveform will emphasize the synchronous components of the signal and suppress the asynchronous components like noise and background effects. The spectrum of the synchronously averaged signal is a linear vector averaged spectrum of the data, having both magnitude and phase information.

Tachometer

device that generates a pulse signal corresponding to the revolution of a shaft, used to measure turning speed. A single pulse per revolution may be used to trigger data acquisition synchronously with shaft rotation.

Time record length

the time required in FFT analysis to acquire the number of samples required to obtain a given number of lines at the sample rate required to achieve the maximum analysis frequency selected.

Transfer function C a spectrum representing the relative magnitude and phase of two signals. For two signals A and B, the transfer function from A to B is the ratio of the cross spectrum from signal A to signal B, divided by the autospectrum (power spectrum) of signal A. Its phase is equal to the phase of the cross spectrum.

Transient

a time-varying signal of finite duration, i.e., having a definite start and finish. May refer to an impulsive signal, such as a hammer blow or the vibration signal from a machine coastdown or spinup. Such signals have finite energy, unlike periodic signals.

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Trigger

the control signal for starting and stopping data acquisition. May be based on an incoming measured signal, an external pulse signal, or an internal clock.

Uniform window

a type of window used for analyzing a signal without shaping. Subject to leakage and amplitude errors if the frequency components are not centered on a line in the spectrum. Suitable for transient signals wholly contained within the analysis time record length and when using external sampling. Also known as a Bartlett, Boxcar, or Rectangular window. Compare Hanning window.

Velocity

the rate of change of displacement of a mechanical system. Units are inches per second (in/s or ips) in English units and m/s, cm/s or mm/s in SI units. Can be measured directly with a velocity pickup or by integrating an acceleration signal from an accelerometer.

Vibration

the oscillatory motion of a mechanical system about a mean position.

Waveform

analog or digital representation of a signal displayed as a plot of level against time.

Windowing

a process of applying a weighting to a waveform signal before computing the FFT in order to minimize leakage and/or the picket fence effect that gives misleading spectrum levels. See also Hanning, Uniform, Exponential, Force/exponential.

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Zoom

a frequency analysis at higher resolution than the baseband spectrum over a limited frequency span in order to see more detail. There are two types: non-destructive zoom and real-time or true zoom. The latter involves re-analyzing the signal (destructive), using frequency translation and digital filtering to obtain the results. Nondestructive zoom involves acquiring more samples in the first instance, giving a potentially higher resolution anywhere in the base-band frequency range. More detail can then be seen merely by expanding the frequency scale in the region of interest.

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Appendix C
TechNotes

Technote 1 – **Overall Level (Analog vs. Digital Integration)**

Technote 2 – **Spectrum and Waveform Units with Analog or Digital Integration**

Technote 3 – **Dual Point Routes**

Technote 4 – **Model 624 Split Signal Adapter**

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TECHNOTE 1
Overall Level (Analog vs. Digital Integration)

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Knoxville, TN 37932
Phone: (865) 675-2110 Fax: (865) 675-3100
Customer Support: (865) 671-4274
http://www.compsys.com

DoctorKnow® TechNote

Title: **Why an Analog Overall reading cannot be taken if Integration mode is Digital.**
Product: **Data Collector/Analyzer**
Program: **Overall\Integration modes**
Version: **All 2110's, 2115's' and 2120's**
Source/Author: **Don Pettitt**

Industry Technology: **Vibration**
Technote Number: **97-00791**

If a customer sets up a measurement point to take a digital integration reading, and has the Overall Mode set to analog, the meter will still take a digital overall reading. Both the integration and overall modes must be set to Analog before an Analog overall can be taken. The reason is because of the way each of the overall modes acquires data.

In the Digital Integration mode, the raw waveform is first changed to a digital signal and then integrated. In the Analog Integration mode, the raw waveform is integrated and then changed to a digital signal. Keep this information in mind as we look at the overall modes.

In Digital Overall mode, the overall is taken after the waveform is digitized and integrated (or integrated and digitized if analog integration is used) and during the averaging process. It does not care how it was integrated because all it sees is a digital representation of an integrated waveform. Whether the signal was digitized before or after digitization, does not matter.

If Analog Overall needs to be taken, it can only be done with an analog signal. Therefore, the signal must be integrated and still remain as an analog signal, which only Analog integration can do. If we allowed the analyzer to do analog overall with digital integration what the customer would get is a spectra in integrated units (in/sec or mils depending on setup) but the overall would be g's. This would cause great confusion.

One way to tell what overall mode the meter is in, is to change live display to OFF (2110 and 2115) or STATUS (2120). After that if you take a reading and if you see an overall number as it counts down the averages, it is in Digital Overall. If you just get the number of averages as it counts down, then at the end after all averages have been taken it says MEASURING OVERALL VALUES, it is in Analog Overall. That is because in the Analog Overall mode, the analyzer takes the main averaged readings, and after it finishes that, it goes back and then takes another reading that is the overall.

TECHNOTE 2
Spectrum and Waveform Units with Analog or Digital Integration

835 Innovation Drive
Knoxville, TN 37932
Phone: (865) 675-2110 Fax: (865) 675-3100
Customer Support: (865) 671-4274
http://www.compsys.com

DoctorKnow® TechNote

Title:	**Settings for Sensor Type and Signal Integration in 21xx Analyzers**
Product:	**Data Collector/Analyzer, MasterTrend**
Program:	**N/A**
Version:	**All**
Technology:	**Vibration**
Technote Number:	**99-01274**

In the analyzer, press **UTILITY >> CHANGE SETUP >> SENSOR TYPE:**

SENSR TYPE: ACCEL, VELOC, DISPLC, etc.
CONVERT TO: ACCEL, VELOC, DISPLC, etc.

In the analyzer, press **UTILITY >> CHANGE SETUP >> MEASUREMNT MODE:**

OVERALL LEVEL MODE: ANALOG or DIGITAL
SIGNAL INTEGRATION MODE: ANALOG or DIGITAL

Integration	Units	Common Abbreviations
Acceleration	G's (RMS)	Acc. or Accel.
Velocity	in/sec (pk)	Vel. or Veloc.
Displacement	mils (pk-pk)	Disp. or Displc.

NOTE: For information on units conversion, see Technotes # 96-00709 and # 98-00919 .

Other Abbreviations

W	Waveform
S	Spectrum

This table below shows how the **Measurement Mode** settings (**Overall Level Mode** on top, **Signal Integration Mode** on bottom) and the **Sensor Type** settings affect the units the data is collected in.

NOTE: If at any time the Signal Integration Mode is set to Digital, the analyzer will take a Digital overall reading even if Overall Level Mode is set to Analog. See Technote # 97-00791 for details.

OVERALL MODE/ INTEG. MODE	SENSOR TYPE *(Convert From --> To)*		SENSOR TYPE *(Convert From --> To)*	
	ACCEL --> VEL		**VEL --> VEL**	
Analog	W	in/sec	W	in/sec
Analog	S	in/sec	S	in/sec
Digital	W	G's	W	in/sec
Digital	S	in/sec	S	in/sec
Digital	W	in/sec	W	in/sec
Analog	S	in/sec	S	in/sec
	ACCEL --> DISP		**VEL --> DISP**	
Analog	W	mils	W	mils
Analog	S	mils	S	mils
Digital	W	G's	W	in/sec
Digital	S	mils	S	mils
Digital	W	mils	W	mils
Analog	S	mils	S	mils
	ACCEL --> ACCEL			
Analog	W	G's		
Analog	S	G's		
Digital	W	G's		
Digital	S	G's		
Digital	W	G's		
Analog	S	G's		
	DISP --> DISP			
Digital or Analog	W	mils		
Digital or Analog	S	mils		

TECHNOTE 3
Dual Point Routes

835 Innovation Drive
Knoxville, TN 37932
Phone: (865) 675-2110 Fax: (865) 675-3100
Customer Support: (865) 671-4274
http://www.compsys.com

DoctorKnow® TechNote

Title: **Dual Channel MasterTrend Route Point Setup**
Product: **Data Collector/Analyzer**
Program: **2120**
Version: **v7.04**
Source/Author: **David Kowal**

Industry Technology: **PDM**
Technote Number: **96-00359**

MasterTrend dual channel route points are setup like single channel route points, except dual channel points require the measurement point "Signal Group/Channel" option, under DBASE/ADD EDIT OLD INFORMATION/MEASUREMENT POINT INFORMATION (screen DE05). Use a group number of 20 and above, with channels 1 and 2. If the 2120 is in the single channel mode, or the group number is less then 20, or if the channel number is 3 or more, or the units type code isn't setup for accel, velocity, or displacement the point will be considered a single channel acquisition. Therefore, single channel point acquisitions can be made while the meter is in the dual channel mode and not all points setup in MasterTrend using the points "Signal Group/Channel" can be acquired as dual channel points.

Dual channel points consist of two points. There must be two points per group (one on channel 1 and the second on channel 2). The same group number can not be used more then once per machine, except for the two dual channel points being grouped together. The same group number can be used on more than one machine in a route. Both points being grouped together must be on the same machine, but don't have to be one after the other. Points setup for channel 1 will be acquired on the A-Channel and channel 2 points will be acquired on the B-Channel of the Model 628 mux.

Starting with version 7.09 firmware several things can be different between the dual point setup. Refer to tech note (98-01063) for options and limitations concerning setups.

Routes are created, loaded, and dumped as they always have been. A route can contain both single and dual channel points. Data acquisition begins by pressing the ENTER key while setting on one of the dual channel points. You can be on the A-Channel point or the B-Channel point when you start the acquisition. Both points will be acquired at the same time when the meter is in the dual channel mode. The dumping of dual channel Off-Route data to MasterTrend is the same as it is for dumping single channel data.

TECHNOTE 4
Model 624 Split Signal Adapter

835 Innovation Drive
Knoxville, TN 37932
Phone: (865) 675-2110 Fax: (865) 675-3100
Customer Support: (865) 671-4274
http://www.compsys.com

DoctorKnow® TechNote

Title: **2120 Independent Sensor Setup and 624 Split Signal adapter:**
Product: **Data Collector/Analyzer**
Program:
Version: **v7.09**
Source/Author: **Kevin Steele**

Industry Technology: **Vibration**
Technote Number: **98-01063**

The 2120-2 can simultaneously acquire data on two Measurement Points with different point configurations and/or AP sets. This feature became available as of v7.09 firmware. The original demand for this feature was to be able to collect a PeakVue spectrum at the same time as a normal vibration spectrum. (For added convenience toward this end, two special adapters have been developed for splitting the raw signal from a single sensor into both channels of the 2120-2 where each channel can then be processed differently.)

This feature will even allow simultaneous acquisition of Volts and Accel inputs by a special use of the existing 628 B-channel adapter as outlined below.

Some important limitations do exist which are also outlined below.

624 Split Signal Input Adapter(s)
A special input adapter, the 624A or 624V, is needed to split one input from a single sensor into both A and B channels at the same time. The 624A adapter is used when sensor power is ON (Accelerometer input). The 624V adapter is used when sensor power is OFF (Volts input). The original 628 adapter is still used to collect data from two separate sensors. Note: The 2120 does not detect which input adapter is connected, so it is up to the operator to use the proper adapter.

Using the 628 adapter to collect both Accel and Volts inputs
The 628 adapter is normally used to collect dual or cross channel measurements from two sensors of the same type. But, it can also be used to collect simultaneous data from both an Accel and a Volts input by being aware of how it works. The 628 adapter plugs into the 2120-2's 25-pin connector. It has two BNC inputs marked A and B. It has a toggle switch to select between Accel and Volts.

However, the toggle switch only affects the A channel input. The B channel input is software controlled by the measurement point configuration, regardless of how the adapter switch is set. Therefore, you can set the toggle switch one way for the A channel and the B channel can still collect either an Accel or Volts input depending on how the measurement point is defined.

Dual Point "Independent" Setup (Options and Limitations)

The 2120 will always attempt to take dual points as a simultaneous acquisition. Some point types, however, cannot be used for dual measurements. Also, certain analysis parameter setups conflict with each other. The following are some instances that will cause the 2120 to display an error message and "unlink" two points so that they must be taken sequentially instead of simultaneously:

1. Temperature, DC Voltage, Keypad, and Shaft Probe cannot be configured as dual points.
2. If one point is set for Normal averaging, then the other point can't use Synchronous Time averaging or Order Tracking.
3. Route based Digital/Analog override for Overall and Integration must be the same for both points.
4. Can't have one point normal and the other use Third Octave.

Also, if the F-max values of the two points cannot be generated at the same time, the points will be taken sequentially instead of simultaneously. In this case, the determination is not made until data acquisition has begun *(because, if you were using order based analysis on a variable speed machine, you would not know the exact F-max values until you entered the rpm and began the measurement)*. The operator will only have to press the ENTER button once to collect both points, and no error message is given.

Note: The F-max value for PeakVue or Demodulation points will always round up to one of the following: (20 Hz, 50 Hz, 100 Hz, 200 Hz, 400 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz, 10kHz).

-Simultaneous acquisition of a Demodulation point and a normal vibration point is not guaranteed unless the normal vibration point also uses (any) F-max from the list above.

-Simultaneous acquisition of a PeakVue point and a normal vibration point is not guaranteed unless the normal vibration point also uses (any) F-max from the list below:

(100 Hz, 200 Hz, 400 Hz, 800 Hz, 1 kHz, 2 kHz, 4 kHz, 10 kHz, 20 kHz).
(One exception is if the PeakVue point is only set to 20Hz. In this case go by the top list.)

In order to ensure both points will have an Fmax from the valid list, on a variable speed machine it may be necessary to switch the Fmax setups from Order based intervals to fixed CPM or Hz based intervals picked from the list. The parameter bands can be kept in order based intervals to ensure proper trending if the machine speed varies.

The following are some of the things that CAN be different between two dual points:

On the Measurement Point setup:

- -Units Type Code (Accel, Vel, Disp, General Dynamic, etc. note: when splitting a single sensor, the sensor type is the same for both points, but the convert-to units can be different.)
- -Sensor Power (On=Accel, Off=Volts note: should be the same for both channels when splitting a single sensor)
- -Sensor Sensitivity (should also be the same for both when splitting a single sensor)
- -Analysis Parameter Set and Alarm Set assignments

On the Analysis Parameter Set:

- F-max in Hz or Orders
- Low Cutoff
- Lines of Resolution
- Number of Averages
- Window Type
- A-Weighting
- SST
- Demodulation and Filter Settings
- PeakVue and Filter Setting
- Extra Time Waveform with its parameters
- Analysis Parameter Bands

General Comments and Cautions

1. Two measurement points collected simultaneously from a single sensor will have the same date and time, so both MasterTrend (RBMware) and the 2120-2 will allow orbit plots. These plots are of course not valid since orbit plots require two sensors spaced at 90 degrees apart.

2. If two points each have analysis parameters that fall outside their F-max, the 2120 will attempt to collect these additional parameters for both points at the same time. The 2120 may perform up to two additional FFT's to try and get the best calculations of these parameters.

3. Peak and Phase data will be taken simultaneously on both channels if both points are configured to collect the same order(s).

4. The waveform overlap value set in the meter will be controlled by the longer of the two waveforms.

Appendix D
Labs

Lab 1 **– Single Channel Phase (Bode Plot) using a 2110, 2115 or 2120 analyzer**

Lab 2 **– Standard Cross-Channel Phase on a 2120-2 Analyzer**

Lab 3 **– Standard Cross-Channel Coherence on a 2120-2 Analyzer**

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Lab
Single Channel Phase

This document provides step-by-step instructions for measuring phase using a CSI 2120 analyzer and tachometer with standard *"data collector"* firmware

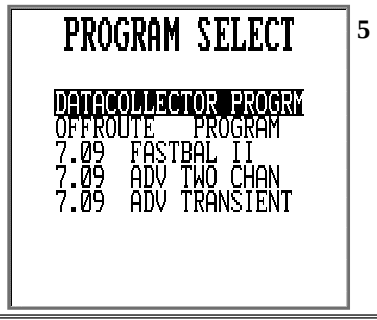
Objectives

✔ Make phase measurements on a motor demonstrator using a tachometer and record the results

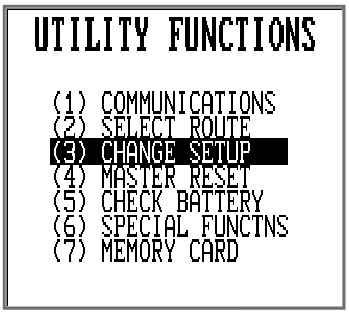
Analyzer Set-up

1. Connect the model 628 or 623 adapter to the 2120-2 analyzer
2. Connect an accelerometer to the channel "A" input of a model 628 adapter or to the "accel" input of a model 623 adapter. *If using a 628 adapter, make sure the adapter toggle switch is pointing towards the front face of the analyzer*
3. Turn on the analyzer
4. Press the "*program select*" key at the top of the analyzer

5. Select the *"Data collector program"*
6. Press the*"Utility key"* at the top of the analyzer
7. Select *"Change Setup"*

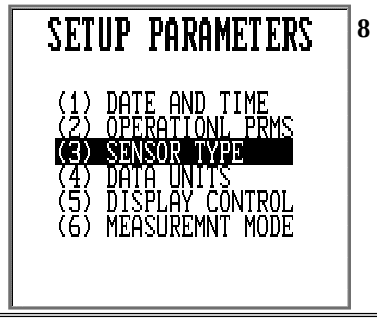


5

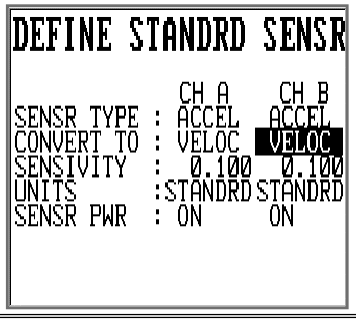


7

8. Select *"Sensor Type"*
9. Setup the sensor as shown below *(two sensors will be displayed only if the analyzer is a 2120-2 with dual channel enabled -- one or both channels can be set-up for the phase measurement)*

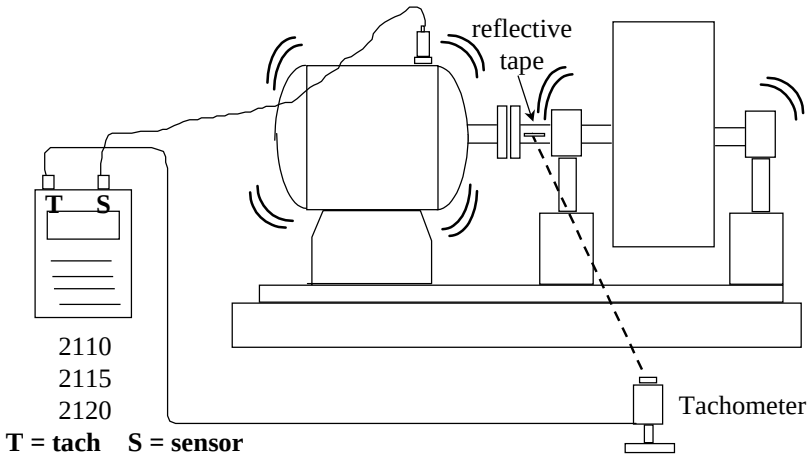


8

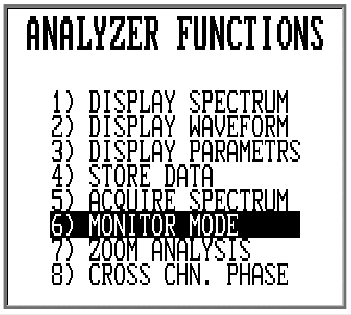

DEFINE STANDRD SENSR
CH A CH B
SENSR TYPE : ACCEL ACCEL
CONVERT TO : VELOC VELOC
SENSIVITY : 0.100 0.100
UNITS :STANDRD STANDRD
SENSR PWR : ON ON

9

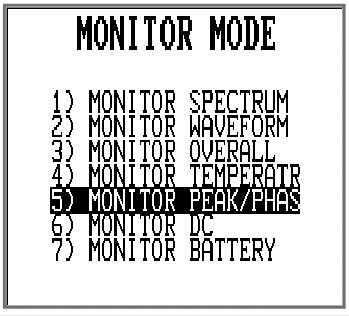
10. Setup the tachometer as shown below



11. Press the *"Analyze key"* at the top of the analyzer
12. Select *"Monitor Mode"*
13. Choose "Monitor Peak/Phase"



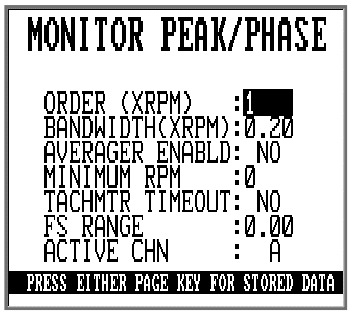
12



13

14. Enter the single frequency setup information

14



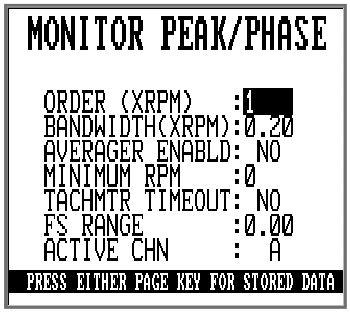
Order: Enter the Synchronous frequency of interest

Bandwidth: Enter the width of the tracking filter (.02 - 1.0).

Width = Peak x bandwidth

All frequencies outside of this window will be attenuated *(0.2 recommended)*

Averager: Vector averages all data *(usually set to no)*



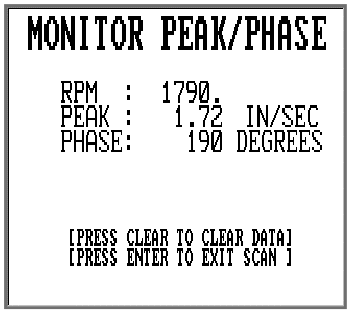
Minimum rpm: No data is collected if speed is less than this value

FS Range: Sets the input range for the analyzer. Zero causes an autorange

Active Channel: Only displayed for dual channel analyzers.

15. Place the accelerometer at the first measurement position and direction on the machine
16. The machine should be operating normally during the phase testing

17. Press the *"Enter key"* to begin the measurement -- speed, phase and magnitude are displayed *(note: the speed display will always show shaft turning speed regardless of the "order" chosen in the set-up screen)*
18. Phase and magnitude should remain steady during the measurement

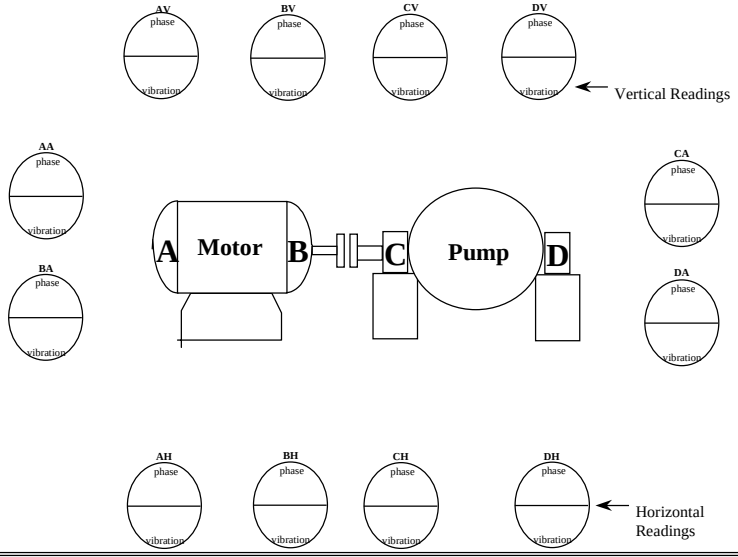


19. Record the phase and magnitude in a table like the one shown below or in a phase test diagram *(as shown on the next page)*

Motor Demo
Mag & Phase at 1x

Point	Mag	Phase
MOH		
MOV		
MOA		
MIH		
MIV		
MIA		

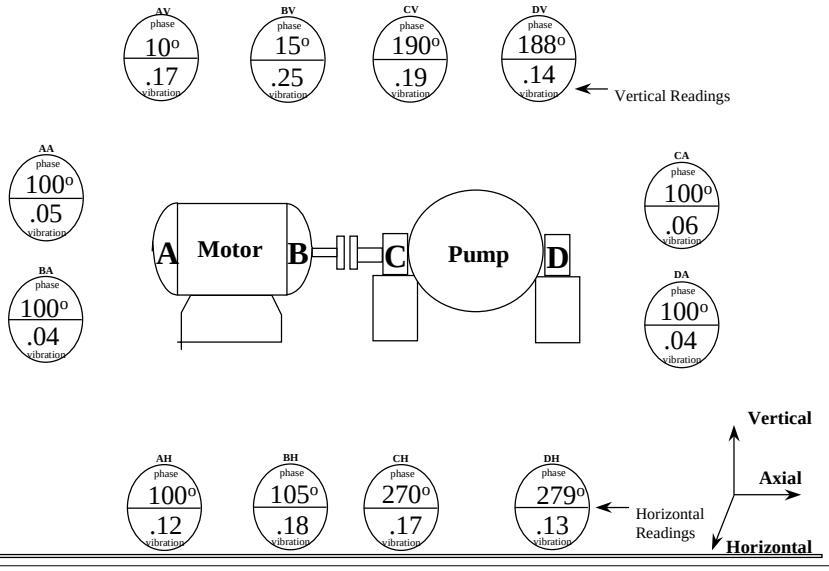
Sample Phase Study Diagram

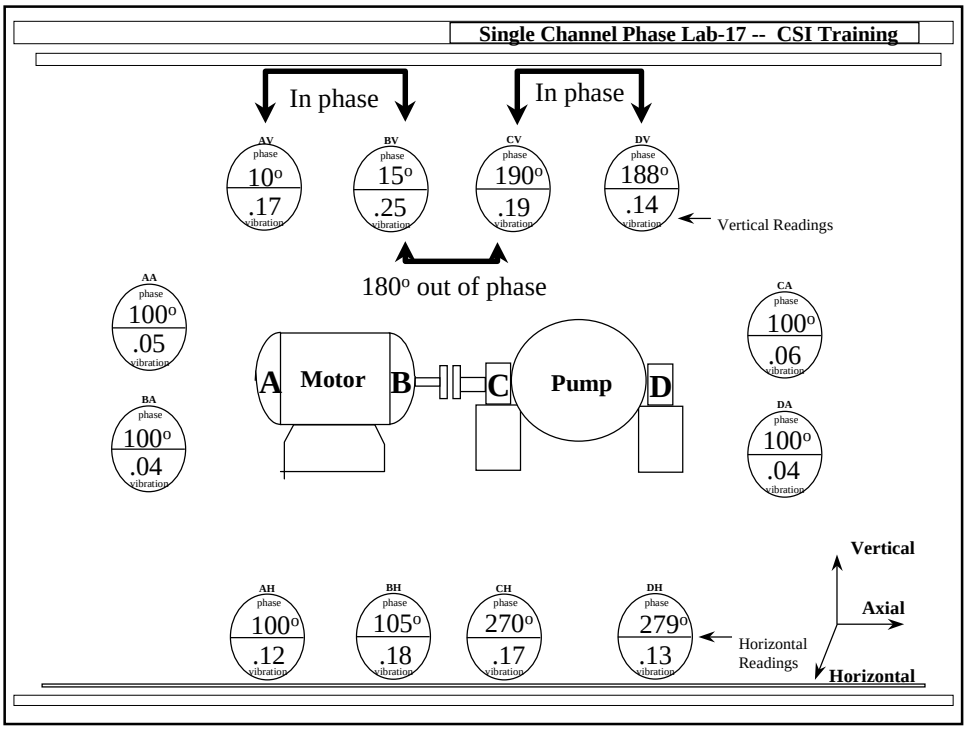


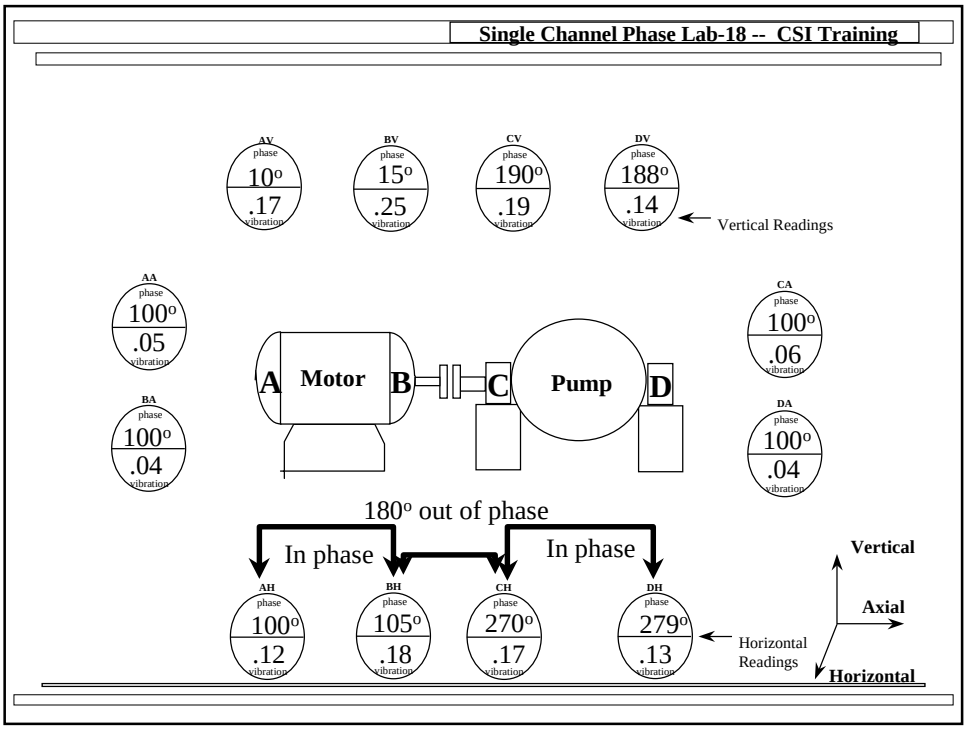
Single Channel Phase Lab-15 -- CSI Training

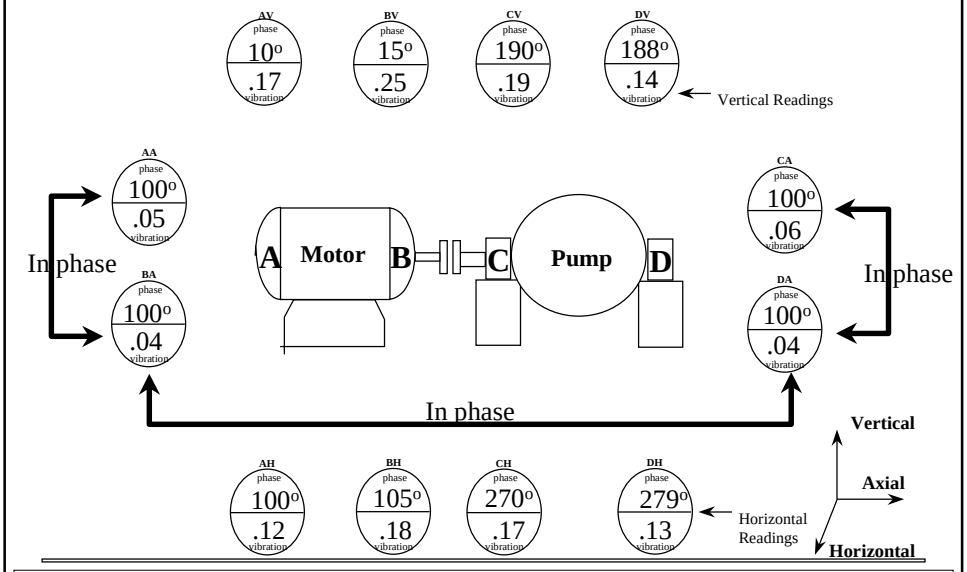
20. Move the sensor to the next measurement position/direction. Press Clear to reset then repeat steps 18 - 20 for all remaining measurement positions
21. Once all of the measurement positions/directions have been measured, the phase data must be analyzed or used in an ODS program.

Single Channel Phase Lab-16 -- CSI Training




Single Channel Phase Lab-17 -- CSI Training
In phase
In phase
AV phase 10° .17 vibration
BV phase 15° .25 vibration
CV phase 190° .19 vibration
DV phase 188° .14 vibration
Vertical Readings
180° out of phase
AA phase 100° .05 vibration
BA phase 100° .04 vibration
A Motor B C Pump D
CA phase 100° .06 vibration
DA phase 100° .04 vibration
AH phase 100° .12 vibration
BH phase 105° .18 vibration
CH phase 270° .17 vibration
DH phase 279° .13 vibration
Horizontal Readings
Vertical
Axial
Horizontal


Single Channel Phase Lab-18 -- CSI Training
AV phase 10° .17 vibration
BV phase 15° .25 vibration
CV phase 190° .19 vibration
DV phase 188° .14 vibration
Vertical Readings
AA phase 100° .05 vibration
BA phase 100° .04 vibration
A Motor B C Pump D
CA phase 100° .06 vibration
DA phase 100° .04 vibration
180° out of phase
In phase
In phase
AH phase 100° .12 vibration
BH phase 105° .18 vibration
CH phase 270° .17 vibration
DH phase 279° .13 vibration
Horizontal Readings
Vertical
Axial
Horizontal



Analysis

Parallel misalignment exists based on higher vibration levels near the coupling and radial phase shifts of about 180° across the coupling.

Review

Peak/Phase data can be measured using a CSI 2115 or 2120 analyzer with standard *"data collector"* firmware and a tachometer.

Peak/Phase data measured with a tachometer is limited to synchronous peaks and must be manually recorded in a phase table then analyzed.

Phase analysis is a tool that the analyst can use to identify vibration sources.

Blank

Single Channel Phase Lab-23 -- CSI Training

Blank

Single Channel Phase Lab-24 -- CSI Training

Blank

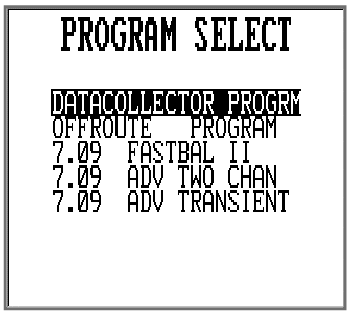
Lab
2120-2 Standard Cross Channel Phase

This document provides step-by-step instructions for measuring cross phase using a CSI 2120-2 analyzer with standard *"data collector"* firmware

Objectives

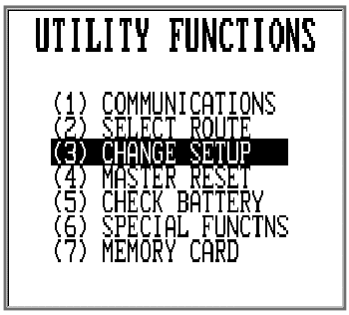
✔ Make cross phase measurements on a motor demonstrator and record the results

1. Connect the model 628, dual channel adapter to the 2120-2 analyzer
2. Connect two accelerometers to the 628 inputs and make sure the adapter toggle switch is pointing towards the front face of the analyzer
3. Turn on the 2120-2
4. Press the *"program select"* key at the top of the analyzer
5. Select the Data collector program

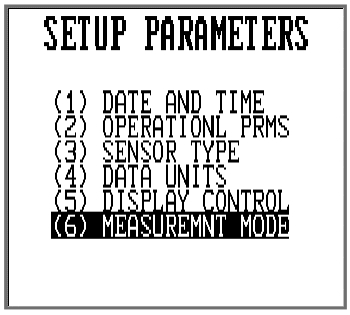


5

6. Press the *Utility key* at the top of the analyzer
7. Select *"Change Setup"*
8. Select *"Measurement Mode"*

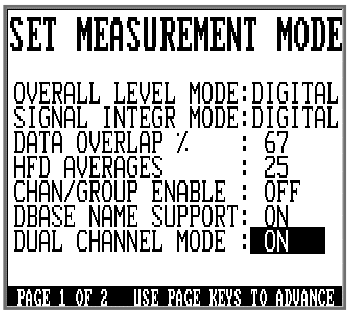


7

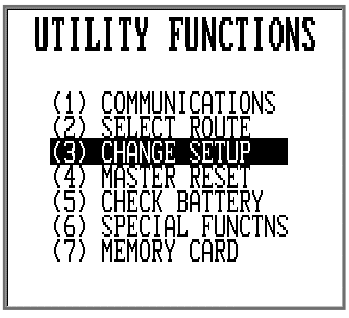


8

9. Turn the dual channel mode to "ON"
10. Press the *Utility key* at the top of the analyzer
11. Select *"Change Setup"*

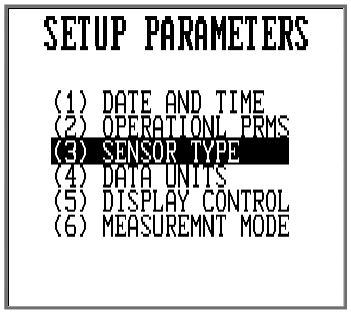

SET MEASUREMENT MODE
OVERALL LEVEL MODE:DIGITAL
SIGNAL INTEGR MODE:DIGITAL
DATA OVERLAP % : 67
HFD AVERAGES : 25
CHAN/GROUP ENABLE : OFF
DBASE NAME SUPPORT: ON
DUAL CHANNEL MODE : ON
PAGE 1 OF 2 USE PAGE KEYS TO ADVANCE

9

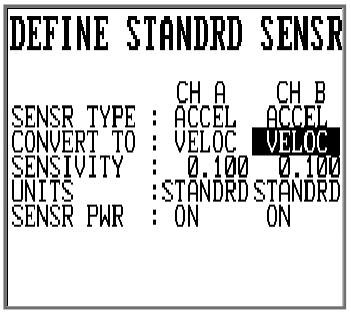


11

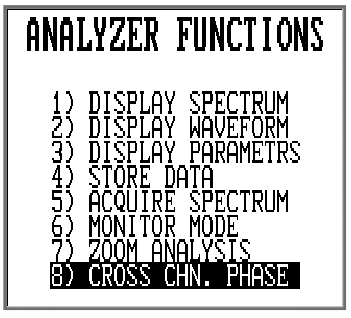
12. Select *"Sensor Type"*
13. Setup the sensor as shown below. Don't mix sensor types! *Convert to* units can be any type as long as A and B are the same



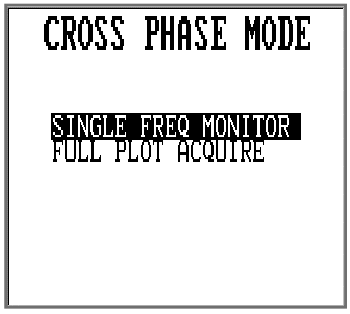
12


DEFINE STANDRD SENSR
CH A CH B
SENSR TYPE : ACCEL ACCEL
CONVERT TO : VELOC VELOC
SENSIVITY : 0.100 0.100
UNITS :STANDRD STANDRD
SENSR PWR : ON ON

14. Press the *Analyze key* at the top of the analyzer
15. Select *"Cross Chn. Phase"*
16. Two methods of measurement are provided. Both will be described in this procedure. Choose "Single frequency monitor"



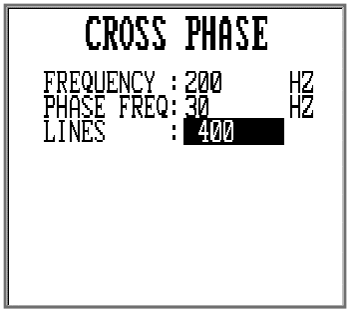
15



16

17. Enter the single frequency setup information

17

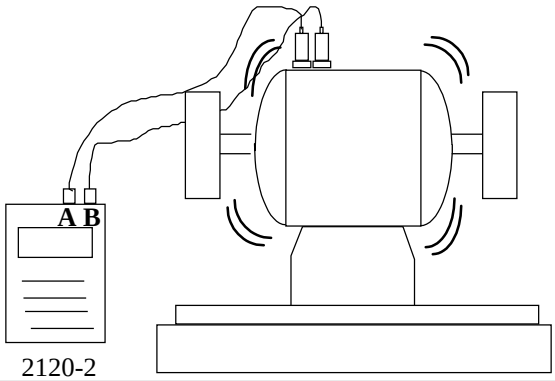


Frequency: Enter the F_{max} for the measurement *(must be higher than the phase frequency.*

Phase Frequency: Enter the frequency of interest for phase data

Lines: Enter the lines of resolution for the measurement

18. Place sensor "A" on the OB motor bearing in the vertical direction. Place sensor "B" next to sensor "A" in the same direction. *Turn on the motor demonstrator.*



2120-2

19. Press enter on the analyzer and read the cross phase value.

19

CROSS PHASE

EXACT FREQ :29.830 HZ
AVERAGES :6
CHN A PEAK : 0.2113 IN/SEC
CHN B PEAK : 0.2461 IN/SEC
CROSS PHASE: 18 DEGS
COHERENCE : 1.00

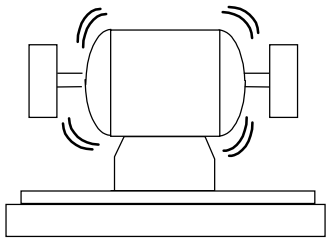
CLEAR AVERG | RESET FREQ | PAUSE

The cross phase is the phase shift between the two sensors. A cross phase of 0^o means both sensors read the same phase at the measured frequency. Two sensors next to each other in the same direction should have little or no phase shift .

Record the cross phase value between 4-10 averages.

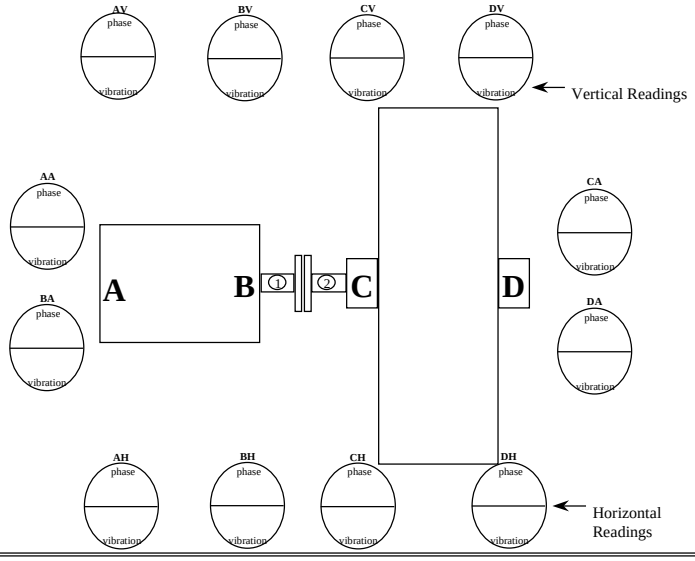
20. Write the phase and magnitude values for sensor “B” in the table below.
21. Do not move sensor “A”. Move sensor “B” to the other measurement positions. Press F1-Clear Averager then repeat steps 19 and 20.

Point	Mag	Phase
MOH		
MOV		
MIH		
MIV		
MIA		

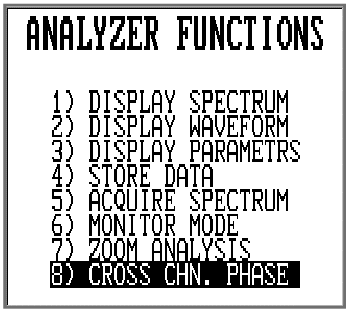


Motor Demo Mag & Phase at 1x

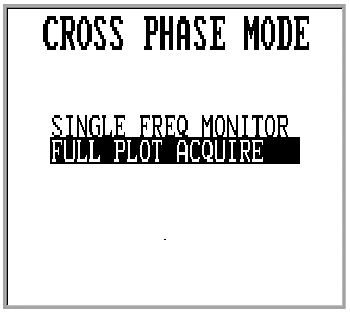
Sample Phase Study Diagram



22. Press the *Analyze key* at the top of the analyzer
23. Select *"Cross Chn. Phase"*
24. Choose "Full Plot Acquire". This option should be used if you are interested in phase and amplitude data at more than one frequency.



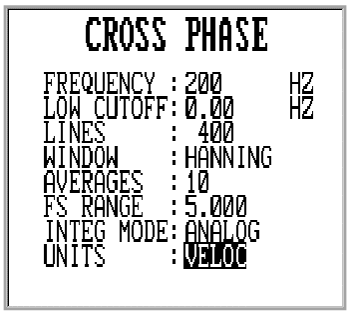
23



24

25. Setup the full plot acquire measurement

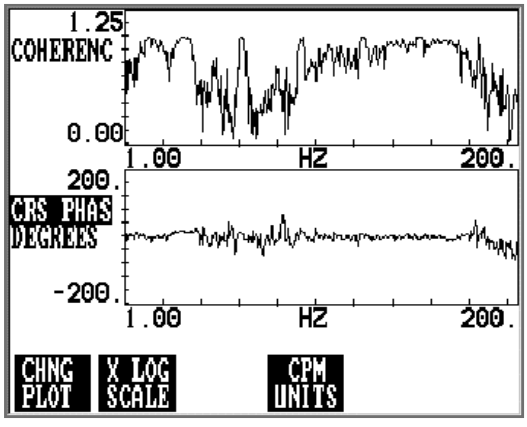
25



Frequency: Enter the F_{max} for the measurement
Low Cutoff: Data below this frequency is not included
Lines: Enter the lines of resolution for the measurement
Window: Usually Hanning
Averages: Use 4-10 averages
Integration Mode: Usually set to analog
Units: Specifies spectrum units

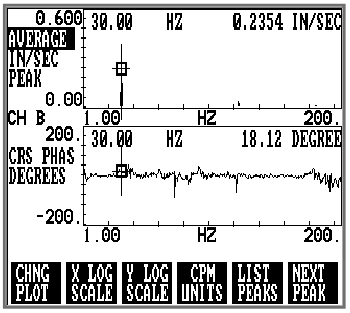
26. Press enter to begin the measurement
27. When finished the display will show phase and coherence across the selected frequency range

27



28. Press F1 - Change Plot. Press any numeric key to toggle through the display options and change the display in the upper plot window to Channel B spectrum. and then press enter.

29. Move the cursor to each frequency of interest and read the phase and magnitude values. Page-up/page-down controls the active cursor.



29

30. Measure the phase and magnitude values at one or more of the motor demonstrator positions previously measured. Compare the results with the tabular data in step 20.

When using the *"cross phase"* function in the data collector mode, write down the results at any frequency of interest.

The cross phase function in the *"data collector"* mode has no provision for data storage.

Review

Cross phase between two sensors can be measured using a 2120-2 analyzer and standard *"data collector"* firmware.

Cross phase measurements do not require a tachometer and are made without interrupting machine operation.

Operational Deflection Shape testing uses cross phase measurements

Blank

Lab
2120-2 Standard Cross Channel Coherence

This document provides step-by-step instructions for measuring coherence using a CSI 2120-2 analyzer with standard *"data collector"* firmware

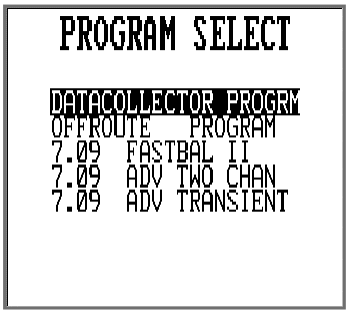
Objectives

✔ Make coherence measurements under the following conditions:

1. With two sensors on a single motor demonstrator

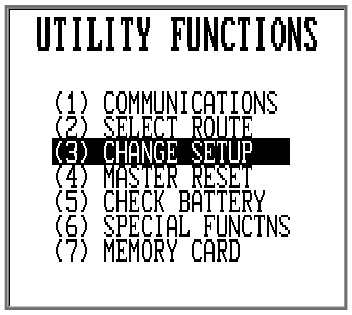
2. With one sensor on one motor and another sensor on a second motor where both motors have the same rotational speed

1. Connect the model 628, dual channel adapter to the 2120-2 analyzer.
2. Connect two accelerometers to the 628 inputs
3. Turn on the 2120-2 and make sure the adapter toggle switch is pointing towards the front face of the analyzer
4. Press the *"program select"* key at the top of the analyzer
5. Select the Data collector program

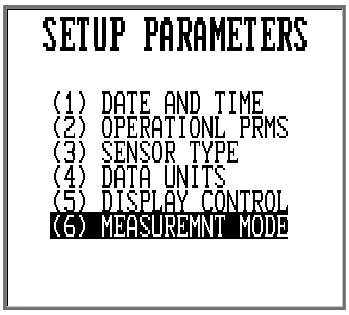


5

6. Press the *Utility key* at the top of the analyzer
7. Select *"Change Setup"*
8. Select *"Measurement Mode"*

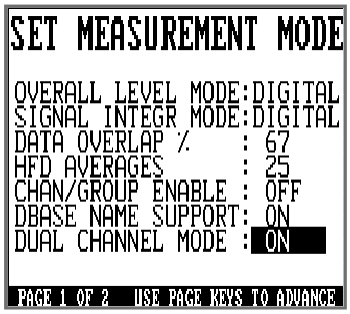


7

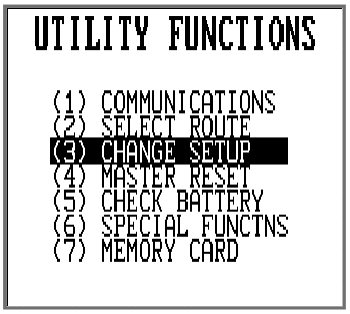


8

9. Turn the dual channel mode to "ON"
10. Press the *Utility key* at the top of the analyzer
11. Select *"Change Setup"*

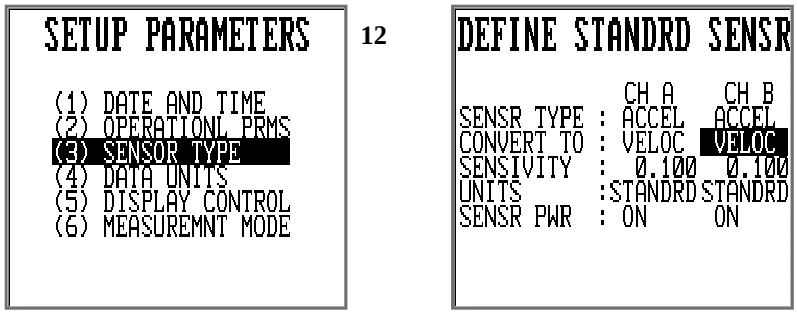

SET MEASUREMENT MODE
OVERALL LEVEL MODE:DIGITAL
SIGNAL INTEGR MODE:DIGITAL
DATA OVERLAP %: 67
HFD AVERAGES: 25
CHAN/GROUP ENABLE: OFF
DBASE NAME SUPPORT: ON
DUAL CHANNEL MODE: ON
PAGE 1 OF 2 USE PAGE KEYS TO ADVANCE

9



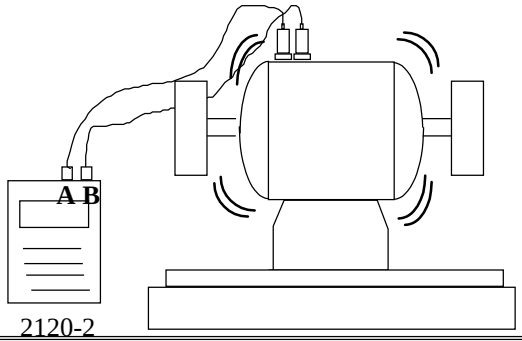
11

12. Select *"Sensor Type"*
13. Setup the sensor as shown below. Don't mix sensor types! *Convert to* units can be any type as long as A and B are the same



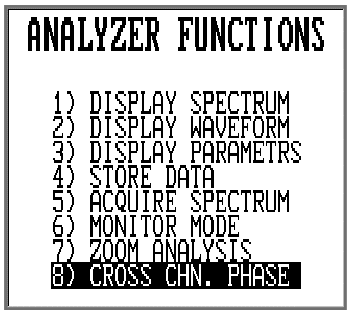
TEST 1

14. Place sensor "A" on the OB motor bearing in the vertical direction. Place sensor "B" next to sensor "A" in the same direction. *Turn on the motor demonstrator*

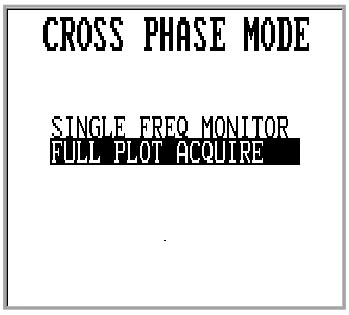


2120-2

15. Press the *Analyze key* at the top of the analyzer
16. Select *"Cross Chn. Phase"*
17. Choose "Full Plot Acquire"

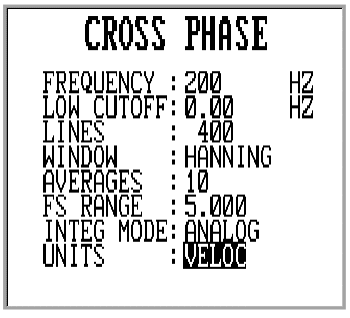


16



17

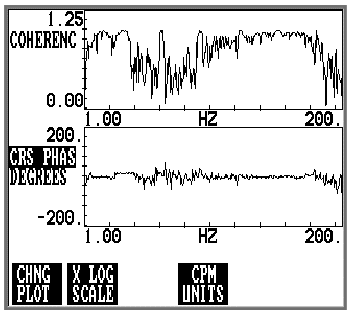
18. Setup the full plot acquire measurement



Frequency: Enter the F_{max} for the measurement
Low Cutoff: Data below this frequency is not included
Lines: Enter the lines of resolution for the measurement
Window: Usually Hanning
Averages: Use 4-10 averages
Integration Mode: Usually set to analog
Units: Specifies spectrum units

19. Press enter on the analyzer to start the measurement. When finished, a plot of coherence and phase will be displayed across the selected frequency range

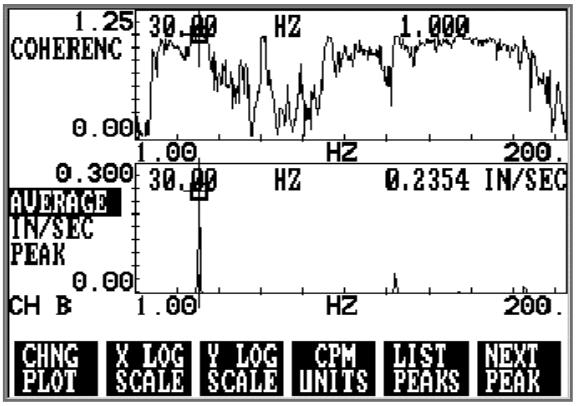
19



21. Press F1 - Change Plot. Press any numeric key to toggle through the display options and change the display in the lower plot window to Channel B spectrum. and then press enter

22. Move the cursor to the peak at shaft speed *(about 29.8 Hz.)* Press *page-up* to switch to the upper trace. Move the cursor to the same frequency

23. Read the coherence value. A coherence value of **0** means the "A" and "B" signals **are not** phase related. A coherence value of **1** means the "A" and "B" signals **are** phase related.

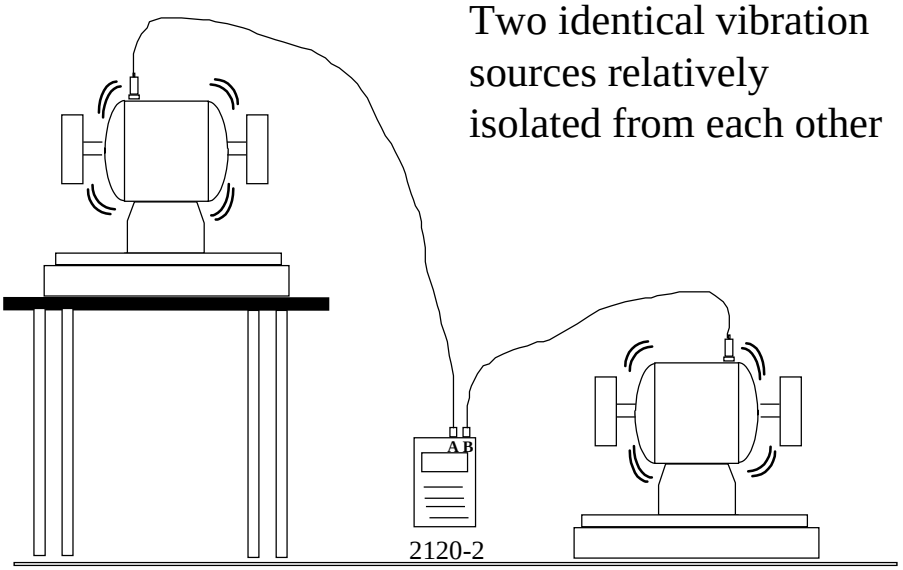


23

24. At each frequency, the coherence will be somewhere between zero and one. If coherence is high it simply means that the source of the vibration is common to both sensors

TEST 2

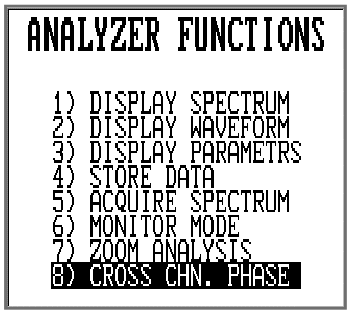
25. Put one motor demonstrator on a table and another on the floor or on a different table. Both motors should be 1800 rpm.
26. Place sensor “A” on one motor in the vertical direction. Place sensor “B” on the other motor in the vertical direction. *Turn on the motor demonstrators.*



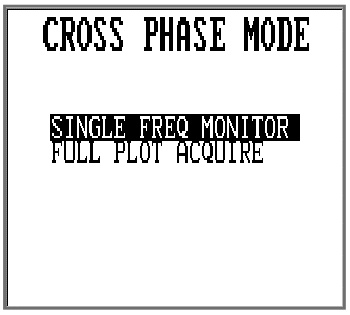
Two identical vibration sources relatively isolated from each other

For this exercise, watch the coherence in a live mode by using “Single Frequency Monitor”

27. Press the *Analyze key* at the top of the analyzer
28. Select *“Cross Chn. Phase”*
29. Choose “Single frequency monitor”

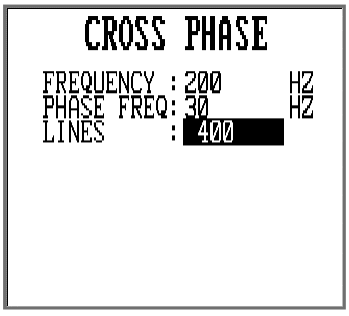


28



29

30. Enter the single frequency setup information



19. Press enter on the analyzer and read the coherence value at motor rotational speed

Unlike test 1, the coherence value should be near zero. Even though, the two motors rotate at almost the exact same speed, the two signals are different *(not in phase with each other)*. The vibrations are not related. The sources are different.

When using the *"coherence"* function in the data collector mode, write down the results at any frequency of interest.

The cross phase function in the *"data collector"* mode has no provision for data storage.

Review

The coherence between two sensors can be measured using a 2120-2 analyzer and standard *"data collector"* firmware.

Coherence measures how related two signals are. A high coherence value means one or more of the following:

"A" caused "B"
"B" caused "A"
The system is linear
"A" and "B" are caused by something else

Blank

Cross Channel Coherence Lab-23 -- CSI Training

Cross Channel Coherence Lab-24 -- CSI Training

Explanation of the Autocorrelation Coefficient Function

Appendix E

Introduction

In this appendix, the objective is to introduce the autocorrelation coefficient function from a mathematical perspective followed by an example to assist the user in developing a "feel" for its properties and how it can assist the analyst in an overall diagnostic effort.

In the next section, the mathematical definitions are presented (extracted from Ref. 9) with discussions relative to their use in machine condition monitoring.

In the last section, an example using the LABview program is presented. Here, noise will be introduced to assist in developing a "feel" for how the autocorrelation coefficient function responds when a signal contains periodic events mixed in with random noise.

CSi means Reliability Training

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Basic Discussion of Autocorrelation Coefficient Function

The basic mathematical definition of the autocorrelation function (from Ref. 9) is:

$$R_x(\tau) = \underset{T \to \infty}{Lim} \frac{1}{T} \int_0^7 x(t)\ x(t+\tau)dt$$

Equation (16.1)

The various quantities in Equation (16.1) are:

1.	x(t) represents the value of the signal x, at the time t.
2.	$R_x(\tau)$ represent the value of the autocorrelation function at the time (referred to as delay time t), derived from and continuous with time signal x(t).
3.	T is the total time for which the integration defined in Equation (16.1) is carried out. The "$\to\infty$" represents that the integration is carried out for a long period of time.

The spectral data we normally rely upon in our normal vibration analysis is compiled by first computing the PSD (power spectral density) function using the FFT algorithms for Fourier transformation and then, with appropriate normalization, taking the square root of the normalized PSD function at each frequency point. Therefore, we should be able to compute the autocorrelation function by first contracting the PSD versus frequency for each frequency point from the spectral data followed by inverse Fourier transformation (which is accomplished through the same FFT algorithms). If we pursue this method, it is difficult to generate the physical understanding we are seeking. Thus we proceed directly from the defining equation, Equation (16.1).

In Equation (16.1), it is assumed that the function (signal) is continuous and has no limit. The signals analyzed are converted from continuous (analog) to discrete (digital) through an A/D converter. We limit the bandwidth of the analog signal by passing its output signal or data through a low pass (anti-aliasing) filter to eliminate any aliasing.

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In the digital domain, the continuous analog signal is converted to discrete values at sequential discrete times established by the sampling rate. Typically, the discrete transform of X values will consist of a block size of 2^n (n is an integer) points, which are the correct size for further processing using the FFT algorithms. The number of points more commonly used are 1024 for 400 line resolution; 2048 for 800 line resolution, etc.

Assuming a block size of 1024 samples (or "points"), i.e., we have digital values for x(t) at constant Δt intervals (inverse of sampling rate) from the first interval through the 1024^{th} interval. Represent this set of numbers by

$$\{x_i\} = x_1,\ x_2, x_3\ ..., x_{1024},$$

by the product of ["l" times Δt] and Δt is the inverse of the sampling interval. Normalize the set $\{x_i\}$ so that the mean value is zero.

Referring to Equation (16.1), we need the product of x at a specific time t, iΔt, and the value of x at a specific time (t + τ), where τ is the lag time. Let the lag time be represented by (jΔt). Then the integrand x(t) x (t + τ) can by represented at a specific time (iΔt) by ($x_l\ x_{i+j}$). Using this nomenclature, the equation defining the autocorrelation function becomes:

$$R = \frac{1}{M}\sum_{i=1}^{M} x_i x_{i+j},$$

Equation 16.2

where M is equal to or less than N/2 number of points in the $\{x_i\}$. The set will contain both positive and negative numbers. In the summation of the $x_I\ x_{i+j}$ overall i values, some of the products will be positive and some will be negative for all j_s except j = 1. For j = 1, Equation 16.2 becomes the mean square for the set $\{x_i\}$. For the set of numbers making up the autocorrelation function, R_j, the first mean square will always be the largest or, as a minimum, equal to the largest value.

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If the set $\{x_i\}$ represents a random set of numbers, all values of R_j, with the exception of the first sample, will be zero (providing the set is sufficiently long). This is so because the set of numbers in the string of $x_l\ x_{i+j}$ with $j > 1$ will have equal numbers of + and – values. Accordingly, noise contributions to the set $\{x_i\}$ will tend to cancel out leaving components that are periodic, exceeding zero when the lag time (τ or j) corresponds to the period of the periodic events.

Given the properties that the first component in the autocorrelation set $\{R_i\}$ is the largest and the fact that noise tends to disappear in the set $\{R_i\}$, a new function, the autocorrelation coefficient function (C_j) is defined as:

$$C_j = \frac{1}{R_1}\left[R_1, R_2, \cdots R_M\right]$$

Equation 16.3

The C_j values will range between ±1. The noise components in the original signal set $\{x_i\}$ average out to zero. Therefore, the autocorrelation coefficient function, C_j, is a measure of the degree of correlation at each value of j (τ) with highly correlated values approaching ±1. This is one of the properties of this function that makes it a very useful tool for the condition monitoring analysis. A second property is the property that the concept of "harmonics" commonly encountered in spectral analysis do not exist in the autocorrelation domain, i.e., all the energy in the many harmonics sometimes encountered in spectral analysis does not exist in the autocorrelation domain, i.e., all the energy in the many harmonics sometimes encountered in the frequency domain will manifest themselves at the delay time corresponding to the fundamental frequency in the spectral domain.*

Note

** Other components show up which on first glance appear to be harmonics but are not. This will be highlighted in the examples to follow.*

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In Equation (16.1), there was a time, T, over which the integration (summation) is to be carried out. The only qualifier was that T is large. Obviously, T must be defined prior to the collection of the data set $\{x_i\}$. Additionally, the sampling rate that defines $\Delta\tau$ also must be defined. Fortunately, the same rule that specifies the bandwidth and number of revolutions in the frequency domain is applicable in the autocorrelation domain.

For example, assume we wish to have a maximum frequency (bandwidth) which captures the highest fault frequency having 4 or more harmonics. Once F_{max} is chosen, the sampling rate, which defines Δt, is set at 2.56 * F_{max}. Additionally, we need resolution appropriate for resolving the lowest expected fault frequency (generally the case). To resolve cage frequency (FTF), a minimum of 15 shaft revolutions should be captured within each block of data. The conclusion is that the block of time data used to compute spectral data can also be use to compute the autocorrelation coefficient function.

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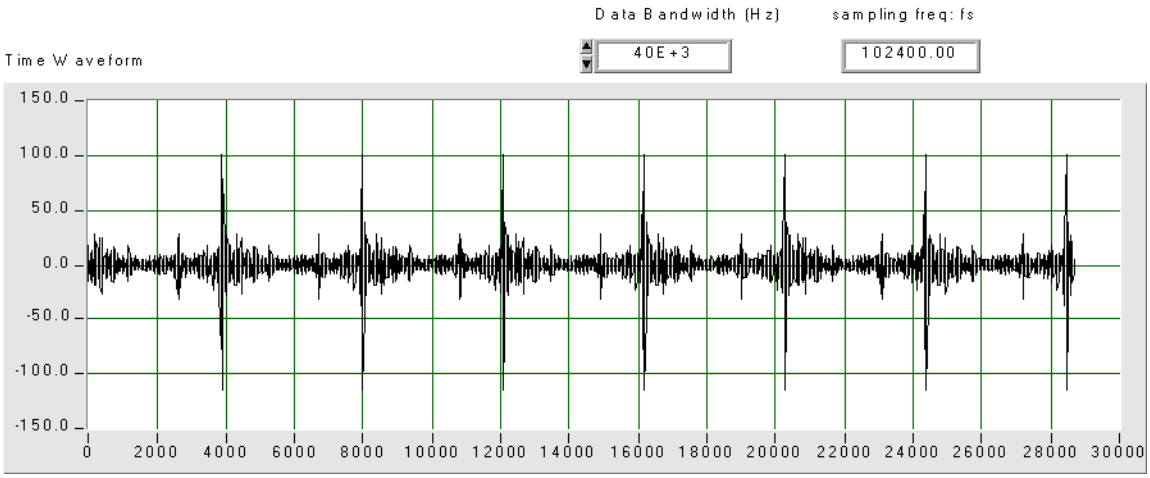
Example of Autocorrelation Coefficient Function

The example presented in this section is computed using the time waveform data presented in the top graph of Figure 11 in section 3.3. This data was the result of taking a data set that had been captured from a bearing experiencing lubrication problems and then repeated seven times (only 6 repetitions will be used here). Clearly the resultant time signal has periodicity since the exact same signal was repeated six times.



The autocorrelation as well as the autocorrelation coefficient functions were computed form the referenced signal using the LabView program, The results are presented in Figure 16.1. The top graph is the time waveform, which contains six repetitions of the beginning signal. The graph in the middle is the autocorrelation function. In both the autocorrelation and the autocorrelation coefficient functions, the total delay time is 1/2 of the total time included in the top graph, which is the maximum delay time that can be used. The frequency of the periodic component in the initial time waveform is the inverse of the delay time of the first large peak in either of the two autocorrelation functions. The degree of periodicity is seen to be 100% in the third or lower graph of Figure B.1 (note the +1 value at the delay time corresponding to the period of the periodic component which corresponds to a 100% degree of periodicity).

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In the third graph of Figure 16.1, we noted that the first large peak occurs at a delay time equal to the period of the periodic component. At a delay time of twice that for the first peak, the magnitude of the peak in the correlation coefficient again is 1.0. The inverse of this delay time would be a period of 1/2 the period for the known periodic component; it is not a second "harmonic" which would be the case in the frequency domain. This high degree of correlation at a period double that of the fundamental is readily apparent in the time data (top graph of Figure 16.1). Basically, the correlation at a delay time of twice the basic periodic events comes from the correlation of every other event.

To illustrate the effect of random noise mixed with the periodic components, noise was added to the time block presented in the top graph of Figure 16.1 and the analysis was repeated. The results are presented in Figure 16.2. From the top graph of Figure 16.2, the signal-to-noise ratio exceeds 2, but the periodic components are readily apparent. The noise signal component is mostly gone in either of the autocorrelation functions (shown in the middle and lower graphs of Figure 16.2). The level of correlation is slightly less (third graph of Figure 16.2 showing about a 0.95 to 0.98 value) for this case where noise was added to the signal in comparison with the previous example where no additional external noise was introduced. In this second case, the degree of correlation would decrease somewhat. Even so, use of the autocorrelation coefficient function still clearly identified the periodic components and noticeably increased the signal-to-noise ratio far above 2, which existed in the original signal (upper graph of Figure 16.2).

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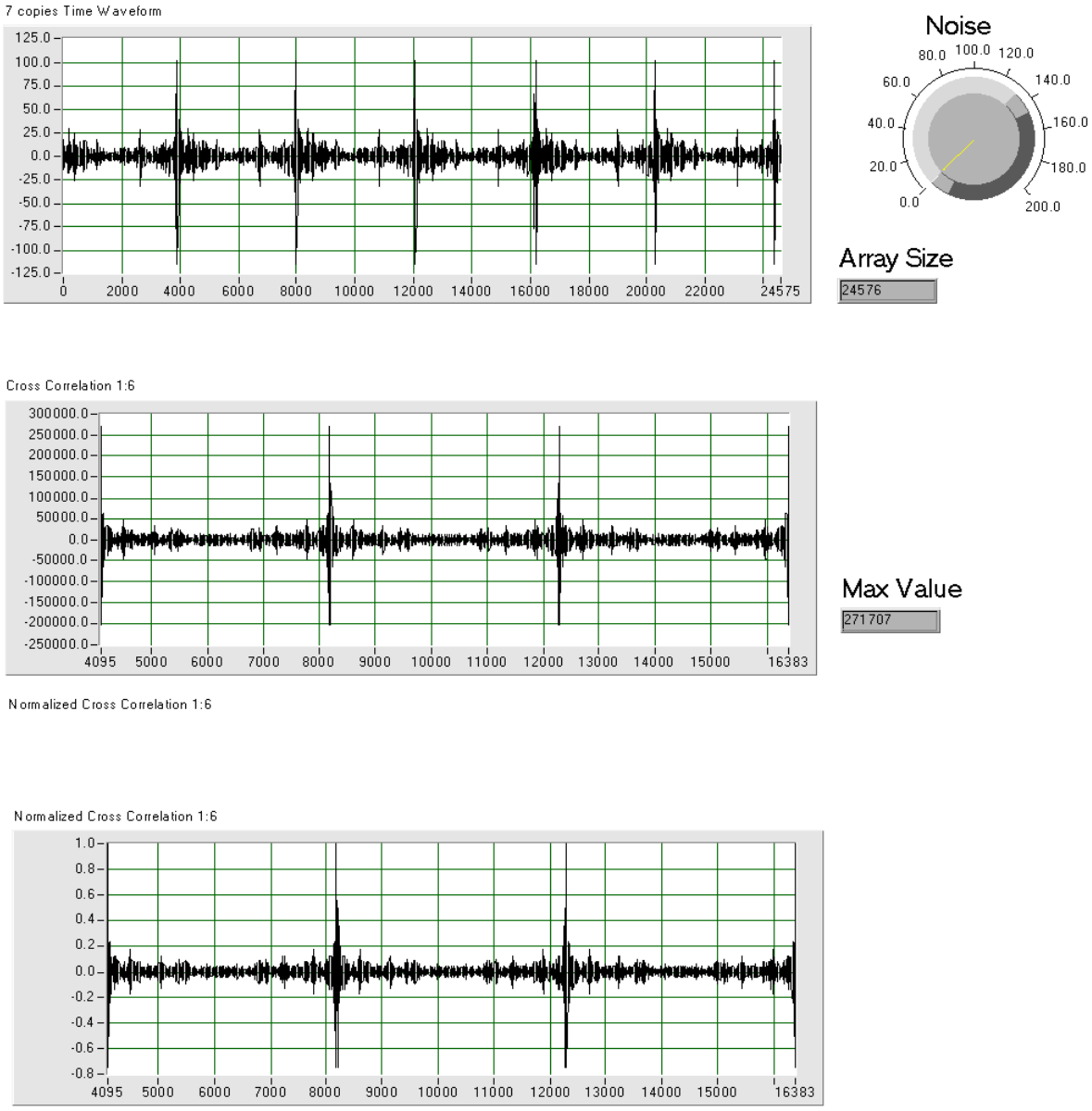

Figure 16.1

Illustration of autocorrelation function (middle graph) and autocorrelation coefficient function (lower graph) computed from time waveform without any noise added (upper graph).

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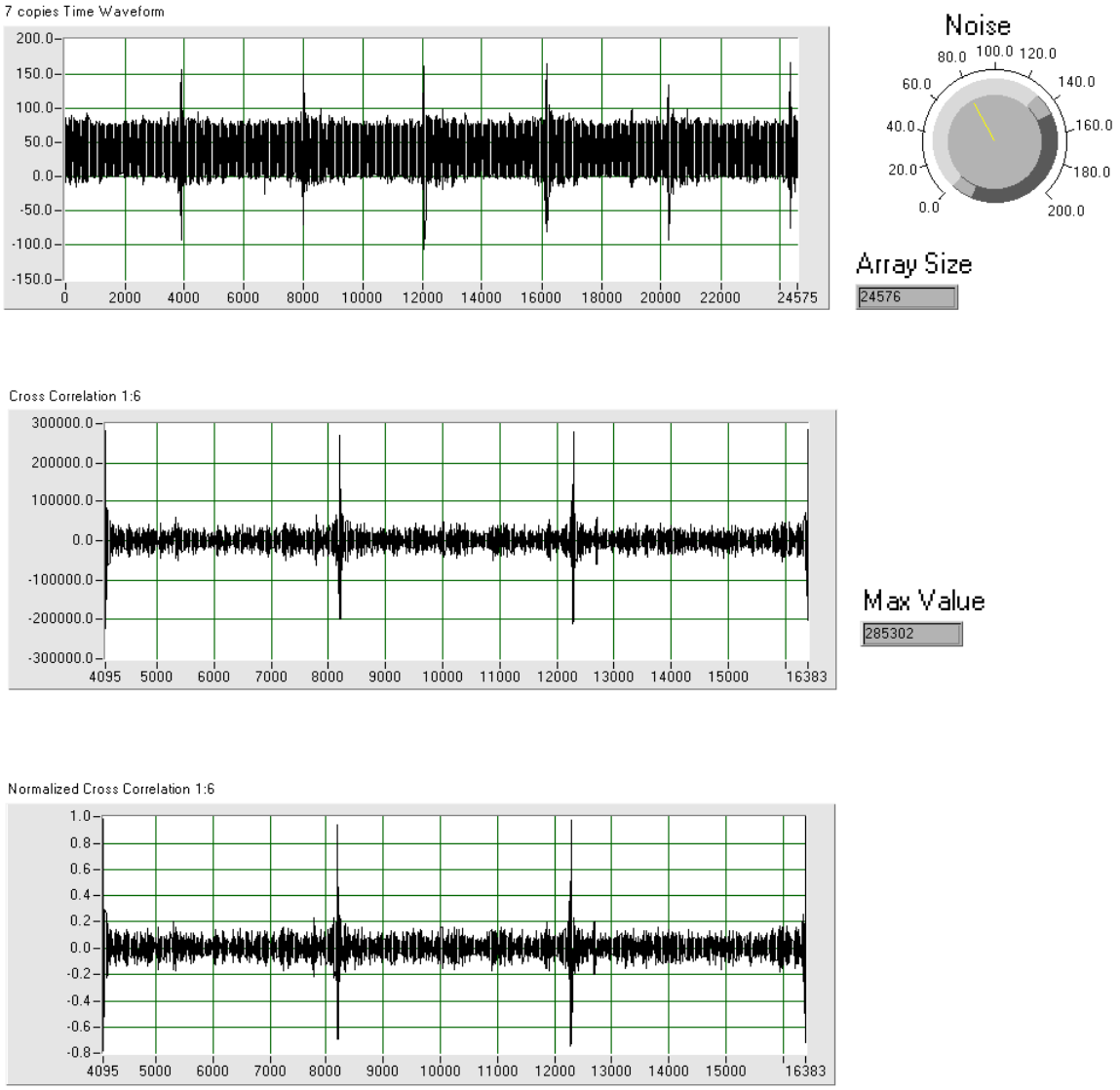

Figure 16.2

Illustration of autocorrelation (middle graph) and Autocorrelation coefficient function (lower graph) Computed from Time Waveform with considerable noise added (upper graph).

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